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UC-707

Draft Summary Report

Phase I of the Hanford Environmental Dose Reconstruction Project

July 1990

Pacific Northwest Laboratory
Richland, Washington 99352

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Technical Steering Panel
Hanford Environmental Dose Reconstruction Project
Department of Ecology
Office of Nuclear and Mixed Waste
MS PV11
Olympia, WA 98504
1-800-545-5581

This report was prepared by staff at the Pacific Northwest Laboratory, which is operated by Battelle Memorial Institute, under the direction of an independent TSP. The work described here was directed and monitored by the TSP; however, this report has not yet been reviewed and approved by the TSP. At the TSP's direction, the report is being made available to the public at the same time it is provided to the TSP. The information contained herein is considered preliminary until it undergoes review by the TSP.

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Preface

Work Was Prompted by Public Concern

The work described in this report was prompted by the public's concern about potential effects from radioactive materials released from the Hanford Site. The Hanford Environmental Dose Reconstruction (HEDR) Project was established to estimate radiation doses the public might have received from the Hanford Site since 1944, when facilities began operating.

The HEDR Project, and the issuance of this Draft Summary Report, are under the direction of an independent Technical Steering Panel (TSP) of scientists and members who represent Washington and Oregon states, regional Native American tribes, and the public. The TSP directs, reviews, evaluates, and approves all HEDR Project work. The U.S. Department of Energy (DOE) funds the project but provides no technical review or oversight.

Radiation Doses Are Preliminary

Phase I of the HEDR Project is a "pilot" or "demonstration" phase. The objectives of this initial phase were to

- determine whether enough historical information could be found or reconstructed to be used for dose estimation
- develop and test conceptual and computational models for calculating credible dose estimates.

Preliminary estimates of radiation doses were produced in Phase I because they are needed to achieve these objectives. The reader is cautioned that the dose estimates provided in this and other Phase I HEDR reports are preliminary. As the HEDR Project continues, the dose estimates will change for at least three reasons:

- more complete input information for models will be developed
- the models themselves will be refined
- the size and shape of the geographic study area will change.

Work Brought About Important Innovations

Other work has been done in the United States to estimate the amount of radiation people received from federal nuclear facilities. However, the HEDR Project "broke new ground" by pioneering several innovations:

- The work was directed by an independent panel of experts and representatives of states, Native American tribes, and the public. In the past, the DOE directed and reviewed dose reconstruction work involving its facilities. This role was seen by some as jeopardizing the credibility of the work being performed. The use of a TSP, in contrast, provides independent scientific and public direction by a group other than the one that manages the facilities being investigated.

- The public was invited and encouraged to become involved in, and to have access to, the process and results of dose reconstruction work. This included opening TSP meetings to the public, providing public access to project reports and other materials, and providing public access to the Battelle scientists conducting the dose reconstruction work. Public concerns and information needs were actively sought out and, to the extent possible, addressed in project work and materials.
- Expanding on efforts in other national studies to make dose estimation more accurate, the computer model used to generate HEDR dose estimates was designed to incorporate differences in factors such as age, food habits, geographical location, and food consumption. For example, instead of using one number to try to represent the amount of milk all people in the Phase I study area drank per day, ranges of milk from none to more than a quart per day were used in estimating doses. That is why the preliminary dose estimates are given in ranges, with a likelihood of having received a certain dose: the dose estimates reflect the wide variation in input information. These kinds of dose "distributions" are therefore more realistic than the typical, single-number estimates of radiation amounts.

Thyroid Disease Study is Separate

In the future, some of the HEDR dose estimates will be used in a separate study to determine whether thyroid disease in the region can be related to radioactive iodine released from Hanford. The Hanford Thyroid Disease Study, which was funded at the direction of the U.S. Congress, is being conducted by the Centers for Disease Control and the Fred Hutchinson Cancer Research Center. No other studies are currently planned on health effects from the release of radioactive materials from Hanford.

Hanford Thyroid Disease Study

In 1986, the Hanford Health Effects Review Panel recommended that a study be conducted to determine whether peoples' health was affected by iodine-131 released from Hanford in the 1940s and 1950s. The U.S. Congress appropriated money for the Hanford Thyroid Disease Study, which began in 1988. The purpose of the thyroid disease study is to determine whether exposures to iodine-131 released from Hanford may have caused thyroid diseases.

Hanford Thyroid Disease Study (cont'd)

The thyroid disease study is separate from the HEDR Project. However, the thyroid disease study will use radiation dose information from the HEDR Project to help determine whether health effects can be linked to Hanford radiation.

The thyroid disease study is managed by the federal Centers for Disease Control. The Fred Hutchinson Cancer Research Center in Seattle is conducting the work. In their current pilot study, researchers are randomly selecting, interviewing, and examining several hundred people who lived in southeastern Washington in the 1940s and 1950s. The main study is expected to begin in 1991 and may include more people. Results should be ready in 1993.

Companion Reports are Available

This is one of three draft reports that summarize the first phase of the four-phased HEDR Project. This, the Draft Summary Report, is directed to readers who want a general understanding of the Phase I work and preliminary dose estimates. The two other draft reports—the Draft Air Pathway Report and the Draft Columbia River Pathway Report—are for readers who understand the radiation dose assessment process and want to see more technical detail. Detailed descriptions of the dose reconstruction process are available in more than 20 supporting reports listed in the Appendix to this Draft Summary Report. They are available in the DOE-Richland Public Reading Room.

Acknowledgments

HEDR staff wish to thank people from the following organizations who helped prepare and produce this report:

- Technical Communication Section, Battelle, Pacific Northwest Laboratories
- Duplicating Section, Battelle, Pacific Northwest Laboratories
- Graphics Services, Boeing Computer Services - Richland

Overview of Phase I

For more than 40 years, the U.S. government made plutonium for nuclear weapons at the Hanford Site in southeastern Washington State. Radioactive materials were released to both the air and water from Hanford. People could have been exposed to these materials, called radionuclides, in the ways shown in Figure 1.

The Hanford Environmental Dose Reconstruction (HEDR) Project is a multi-year scientific study to estimate the radiation doses the public may have received as a results of these releases.

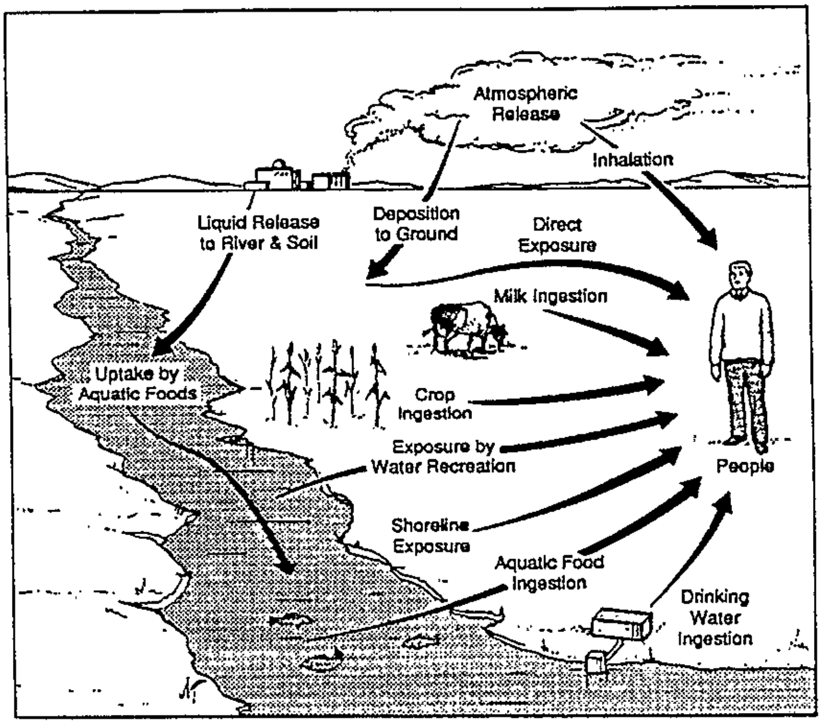

FIGURE 1. Ways People Could Have Been Exposed to Hanford Radionuclides

Approach

The study began in 1988. During the first phase, scientists began to develop and test methods for reconstructing the radiation doses. To do this, scientists found or reconstructed information about the amount and type of radionuclides that were released from Hanford facilities, where they traveled in the environment, and how they reached people. Information about the people who could have been exposed was also found or reconstructed. Scientists then developed a computer model that can estimate doses from radiation exposure received many years ago. All the information that had been gathered was fed into the computer model. Then scientists did a "test run" to see whether the model was working properly.

As part of its "test run," scientists asked the computer model to generate two types of preliminary results: 1) amounts of radionuclides in the environment (air, soil, pasture grass, food, and milk) and 2) preliminary doses people could have received from all the routes of radiation exposure, called exposure pathways. Preliminary dose estimates were made for categories of people who shared certain characteristics (such as location, age, milk consumption patterns) and for the Phase I population as a whole.

Scope

The scope of Phase I was purposely limited so that scientists could check the model early in the project and use the preliminary results to help decide where to focus work for the rest of the project. The geographic study area was the 10 Washington and Oregon counties nearest to Hanford (Figure 2).

Phase I work was divided into looking at the two major exposure pathways: radionuclides that traveled by air and those that traveled by water. The air exposure pathway was studied from 1944 through 1947. Radioactive iodine, called iodine-131, was studied for that time period because the largest quantities of it were released at that time and because it accounts for most of the radiation dose then. Iodine-131 releases occurred when fuel from the Hanford reactors was dissolved in acid to extract plutonium.

The river exposure pathway was studied from 1964 through 1966, when the best river monitoring data were available and when some of the largest quantities of radionuclides were released to the Columbia River. Many different radioactive materials were released to the Columbia River when river water was pumped through Hanford reactors to cool them. The radionuclides that accounted for most of the radiation dose to people—and therefore those studied in Phase I—were phosphorus-32, neptunium-239, zinc-65, arsenic-76, manganese-56, copper-64, sodium-24, and chromium-51.

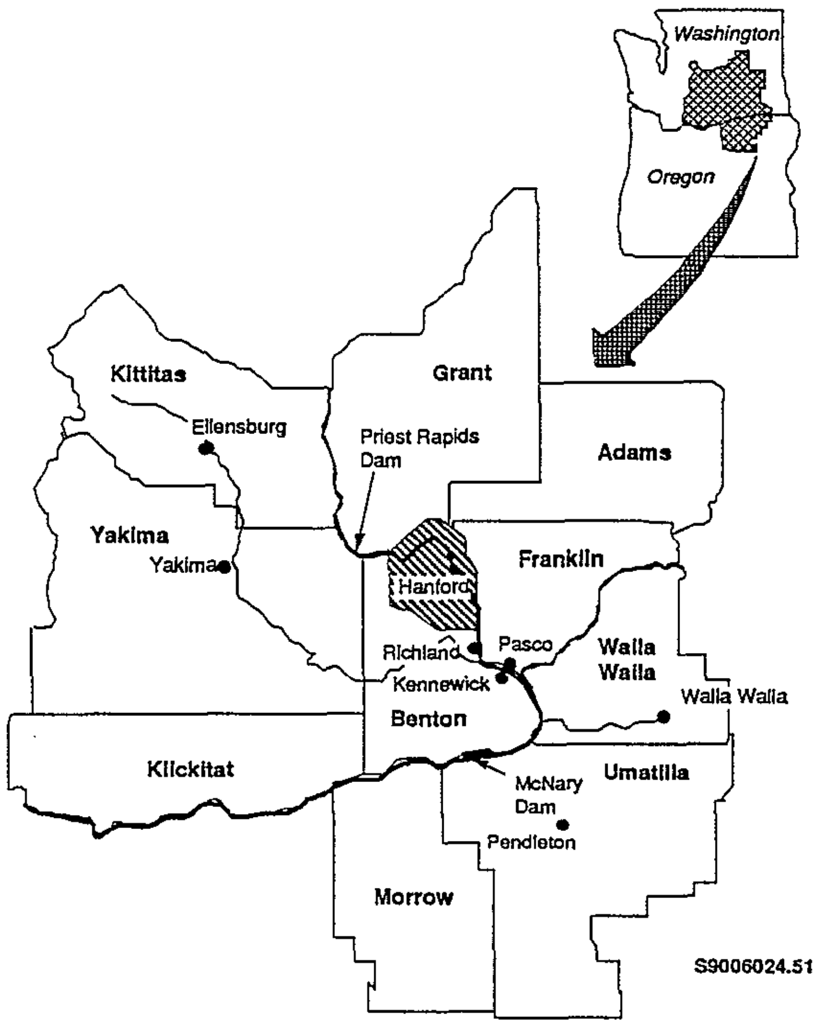

FIGURE 2. 10 Counties Included in Phase I Work

Preliminary Results

Part of testing the model involved comparing its results with independent, but similar, information not calculated by the computer model. This independent information included actual measurements of radioactive materials in the environment (vegetation, fish, and Columbia River water); measurements of radioactive materials in Hanford workers and schoolchildren; and limited, past dose estimates for the public. Preliminary results of the HEDR Project were consistent with the numbers contained in the independent information. The results of this comparison indicated that the computer model was working as intended.

Preliminary Dose Estimates from the Air Exposure Pathway

Part of the computer model's "test output" was preliminary dose estimates. The estimates vary greatly depending on peoples' locations, food habits, ages, and other factors. The highest preliminary doses were from iodine-131 released in the 1940s, primarily from drinking fresh milk from cows that ate pasture grass in counties downwind from Hanford. This way of receiving a radiation dose is called the milk exposure pathway.

Figure 3 shows the dose estimates for the population in the Phase I study area from the milk exposure pathway. The dose estimates are shown in the measurement of dose to the thyroid in rad because iodine-131 is absorbed by the thyroid.

The figure is structured so that the reader can select any dose estimate number given and see what percent of the population might have received a dose higher than that number. The first step in doing this is to select a dose number from the numbers on the dose axis (under the horizontal line at the bottom of the figure). Then the reader moves vertically from that number until hitting the curving line above it. At that point, the reader moves left horizontally from the curving line to the "percent" axis (the vertical line on the left-hand side of the figure). The number on the percent axis is the percent of the Phase I population that could have received a dose higher than the dose number the reader selected.

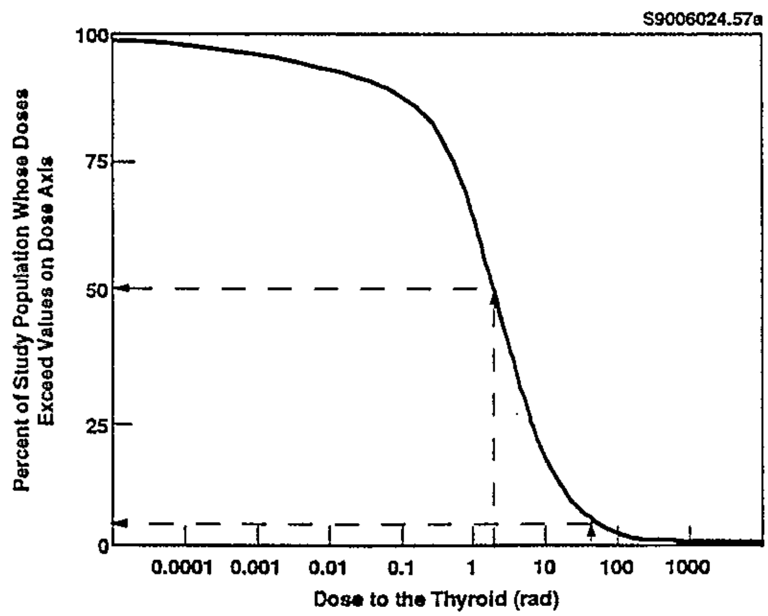

FIGURE 3. Preliminary Dose Estimates for the Phase I Population From the Milk Exposure Pathway, 1945 - 1947

Two examples of how to read this figure are shown on Figure 3 with dotted lines. One example shows that about 50% of the study population could have received doses from the milk exposure pathway higher than 1.7 dose to the thyroid (rad). The other example shows that about 5% of the population could have received doses higher than 33 dose to the thyroid (rad). Another way of saying this is that about 95% of the study population may have received a dose of 33 rad or less to the thyroid.

Two terms that describe the radiation dose estimates are *rad* and *Effective Dose Equivalent (EDE) rem*. The rad expresses the amount of energy deposited by radiation in the body—in this report, the thyroid gland. Effective Dose Equivalent (rem) is used to account for the fact that a radiation dose to one part of the body does not necessarily have the same potential health impact as a dose to another part. The EDE puts different types of radiation doses on an equivalent basis in terms of the potential health risk.

To help people interpret these preliminary radiation doses, it may help to compare them with other radiation people typically receive in daily life, called background radiation (Figure 4). Each year the average American receives a dose of about 0.036 EDE (rem) from background radiation. This radiation is from naturally occurring sources, such as the sun, air, soil, radon gas, and from manmade sources such as medical X-rays. Radiation doses received from releases at Hanford were in addition to such background doses.

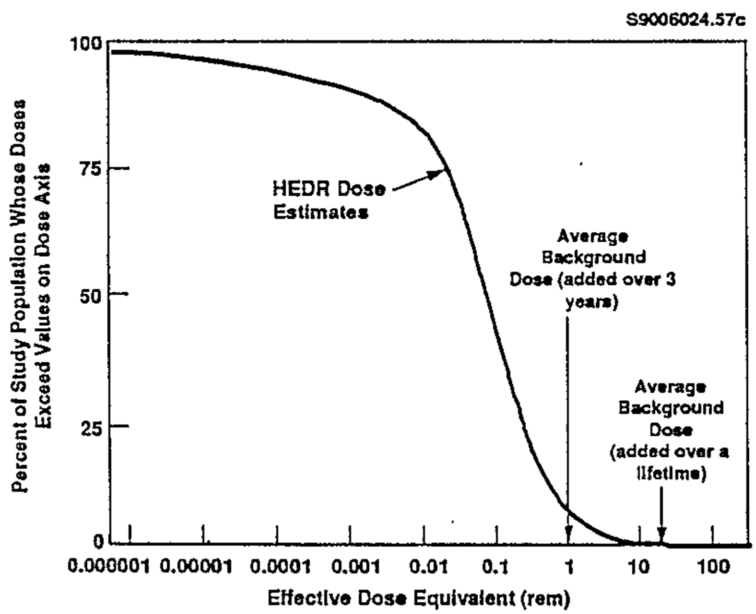

FIGURE 4. Preliminary Dose Estimates from the Milk Exposure Pathway Compared with Background Radiation (HEDR estimates are added over 1945, 1946, and 1947. Background radiation amounts are for the average American, added over 3 years and added over a lifetime)

About 5% of the Phase I study area population, or 13,000 people, might have received doses from the milk exposure pathway for 1945-1947 that were higher than the average American might receive from background sources over three years. About 1% of the study population, or 3,000 people, might have received doses from the milk exposure pathway from 1945-1947 that were higher than the dose the average American receives in an entire lifetime from background radiation.

About 0.004% of the population in the Phase I study area might have received doses to the thyroid greater than a previously published estimate by the Washington State Department of Social and Health Services (DSHS). The DSHS estimated a dose to the thyroid of 2,530 rem to a maximally exposed infant in Pasco, 1945-1947 (Washington State Office of Radiation Protection 1986).

Rem, as used by the DSHS for its thyroid dose estimate, is about equivalent to rad as used in this report. This use of rem should not be confused with EDE (rem) used elsewhere in this report.

Preliminary Dose Estimates from the Columbia River Exposure Pathway

Estimated doses people could have received from radioactive materials released to the Columbia River from Hanford during 1964 through 1966 were much less than doses from contaminated milk during the 1940s. This is because more than 80% of the total dose to people in the downwind portion of the Phase I study area from 1944 to the present is estimated to have come from exposure to iodine-131 released to the air.

The Phase I study area for the Columbia River covered the stretch of the river between Priest Rapids Dam and McNary Dam. Preliminary doses were estimated from eating fish or drinking water from the river or by working or playing near or in the river. In the Phase I study area, only Pasco, Richland, and Kennewick got their city water from the Columbia River.

Figure 5 shows the dose estimates for the Columbia River exposure pathway. About half of the people living in Richland during 1964 through 1966 could have received doses higher than 0.035 EDE (rem) from the Columbia River exposure pathway. About 5% could have received doses higher than 0.076 EDE (rem) (Figure 5). The highest doses were likely received by people who consumed large amounts of fresh fish (more than 20 fish meals per year) caught from the Columbia River above Richland.

The estimated river doses can also be related to background radiation to provide some frame of reference. It is unlikely that anyone who lived in Pasco, Kennewick, or Richland received river exposure doses added over three years—1964, 1965, and 1966—that were higher than the average dose a person might have received in a single year from background radiation (0.36 EDE (rem)).

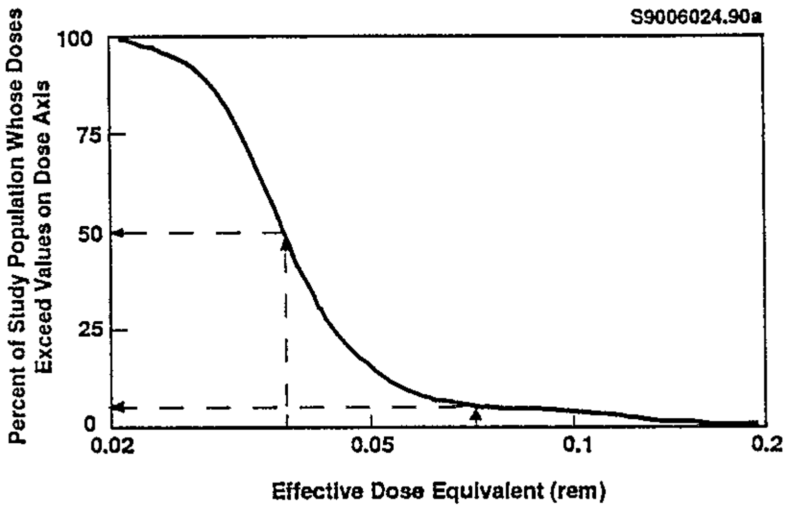

FIGURE 5. Preliminary Dose Estimates from the Columbia River Exposure Pathway, 1964-1966 (Richland residents)

Upcoming Work

Scientists used a simplified computer model in Phase I to get preliminary dose estimates early in the project. The project will continue for at least another three years. In the project's next three phases, scientists will investigate the model to see where it can be changed to obtain more accurate doses. Also, more accurate or detailed historical information will be reconstructed for some aspects of the study, which will result in more specific input information for use with the computer.

Scientists will also investigate potential doses beyond those estimated for Phase I. This will include considering populations outside the 10-county study area and considering additional time periods, exposure pathways, and radionuclides. The final dose estimates will be more certain—or accurate—than the preliminary ones are. In other words, the final estimates will give people a better idea of how likely they were to have received a certain amount of radiation dose. Also, at the end of the project, the computer program will be able to estimate people's individual radiation doses using personal information that they provide.

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1.0 Introduction

This report describes work done in the first phase of the Hanford Environmental Dose Reconstruction (HEDR) Project.

1.1 Project Objectives

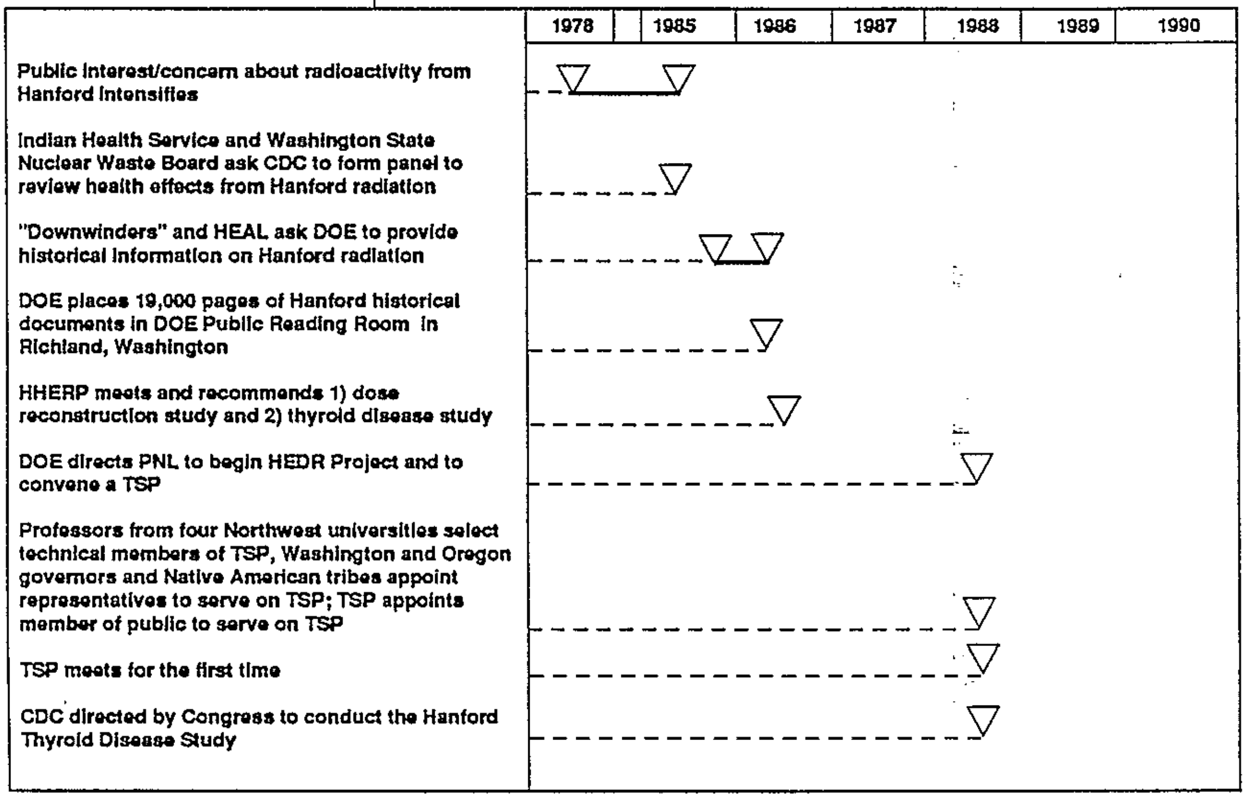
The primary objective of the HEDR Project is to estimate the radiation doses that people could have received from past operations at the Hanford Site. The secondary objective is to make project records available to the public. Copies of project records are maintained in the U.S. Department of Energy (DOE) - Richland Operations Public Reading Room in the Federal Building, Richland, Washington.

1.2 Project History

The HEDR Project was prompted by mounting concern about possible health effects to the public from more than 40 years of nuclear operations at the Hanford Site (Figure 1.1). In 1986, the Hanford Health Effects Review Panel—convened by the Centers for Disease Control at the request of the Washington State Nuclear Waste Board and the Indian Health Service—recommended as a top priority that potential doses from radioactive releases at the Hanford Site be reconstructed.

Representatives from the states of Washington and Oregon, from three regional Native American tribes, and from the DOE agreed that a dose reconstruction study should be funded by the DOE, conducted by Battelle staff at the Pacific Northwest Laboratory, and directed by an independent Technical Steering Panel (TSP). A TSP was deemed necessary to provide credible, independent scientific direction and to provide a forum for participation by the states, Native American tribes, and the public.

Representatives from four Northwest universities selected the technical members of the TSP to direct the dose reconstruction work. Other TSP members include individuals appointed to represent the states of Washington and Oregon, cultural and technical experts nominated by the Native American tribes in the region, and an individual representing the public. The TSP makes decisions on technical direction and reviews and approves all HEDR reports. Though the DOE operates the Hanford Site and funds the HEDR Project, the DOE does not review or approve any aspect of HEDR Project work.



CDC = Centers for Disease Control
DOE = U.S. Department of Energy, Richland Operations
HEAL = Hanford Education Action League
HHERP = Hanford Health Effects Review Panel
PNL = Pacific Northwest Laboratory
TSP = Technical Steering Panel
HEDR = Hanford Environmental Dose Reconstruction (Project)

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FIGURE 1.1 Timeline of Events that Led to Establishment of the HEDR Project

1.3 Scope and Limitations of Phase 1

The HEDR Project is carried out in four consecutive phases. Phase I was limited in scope because its purpose was to develop and test a scientific approach for dose estimation, not to generate definitive dose estimates. Phase I work was limited to populations in the 10 counties surrounding the Hanford Site from 1944 through 1947 and 1964 through 1966. In later phases, the Phase I preliminary estimates will be refined and expanded for residents in other locations at other time periods. In addition, Phase I preliminary estimates were made only for populations and groups of people who shared specific characteristics. In later phases, scientists will be able to estimate radiation doses for actual individuals.

The project's role is limited to estimating *amounts of radiation* received by people. This charter does not include evaluating how Hanford radiation may have affected peoples' health. Similarly, scientists did not attempt to assess the risk associated with having received specific amounts of radiation.

All radionuclides released from Hanford Site facilities were considered in Phase I. This included any radionuclides that may have traveled from Hanford waste disposal areas through soil, into ground water, and into the Columbia River.

In Phase I, scientists studied the routes of radiation exposure that accounted for most of the radiation dose people received. In later phases, additional routes of exposure will be investigated. Such exposure pathways include crops irrigated with contaminated Columbia River water and eaten by people, radionuclides previously deposited in the soil and stirred up again into the air and breathed by people, and radionuclides carried off the Hanford Site by animals that were eaten by people.

Designing a Test Model for Making Dose Estimates

The HEDR Project can be thought of as a project to build a new kind of car that must meet certain standards—for speed, economy, comfort, safety, and gas mileage, for example. Automotive designers would have a good foundation for designing such a car because they have been designing successful cars for years. But what would make this project different is that all these specifications would not have been put together in one car design until now.

Similarly, the HEDR Project builds on other dose reconstruction work, but the HEDR work is new because of the way doses are estimated. Phase I of the HEDR Project was similar to what the "test phase" of a new car design program would be. Automotive designers normally build and test a "trial" model to make sure everything is working properly before they build the final one. Similarly, Phase I of HEDR was a testing phase in which scientists designed, built, and tested the framework for the rest of the study. The "test model" was the computer program, or model, for making dose estimates. Part of designing the model was finding or creating the right kind of information to give the computer model to do its work.

After the model was assembled and fed with information, it was tested to see whether it worked properly. Essentially, scientists "turned on" the computer program, let it perform its thousands of math calculations, and got some rough dose estimates at the end. The computer-generated dose estimates were checked with independent information to verify that the computer was making estimates in the expected ranges. It was, which confirmed that the computer program had been designed properly and was working correctly.

Phase I was similar to designing and building a test model for the new car and demonstrating that it runs. The HEDR computer model runs, but it must be tested and improved to meets its specifications before it is considered finished. In the next three phases of the HEDR Project, the model will be further tested and fine-tuned so that it can make more accurate dose estimates.

1.4 Anatomy of Report

The report first presents background information on the Hanford Site. Next, the dose reconstruction process is described, including the input and output information for the computer model that was used to estimate preliminary radiation doses. The dose estimates are presented. Then, to provide some perspective, the preliminary estimates are compared with background radiation. Independent sources of information—previously published dose estimates and measurements—are compared with the HEDR dose estimates to verify that the preliminary HEDR computer model is working properly.

2.0 Hanford Site History

This section describes the Hanford facilities from which radioactive materials were released and the methods for controlling and monitoring releases.

2.1 Hanford Site

The Hanford Site in southeastern Washington State (Figure 2.1) was established in 1943 as the location for the facilities needed to produce plutonium for atomic bombs used in World War II. Fuel fabrication facilities were used to prepare the fuel for nuclear reactors that irradiated the uranium fuel to create plutonium. The reactors were cooled using Columbia River water. Chemical separation plants were used to separate plutonium from uranium and from fission products created in the fuel during irradiation.

Radioactive Material and Radiation

A radioactive material (or radionuclide) is one that spontaneously emits radiation. Atoms of these materials emit radiation because they have excess energy. Several types of radiation can be emitted when a radioactive atom gets rid of its excess energy. Some radioactive materials emit a particle such as an electron (also called a beta particle), a neutron, or an alpha particle (which is two protons and two neutrons). Other types of radioactive materials emit packets of energy called gamma rays. A gamma ray is physically the same as a ray of light, except it has much more energy.

When an atom of a radioactive material emits radiation, it is called radioactive decay. When a radioactive atom decays, it can turn into a stable version of the same element or it can change into another chemical element. For example, when iodine-131 decays, it turns into a nonradioactive element. A group of radioactive atoms of the same kind will decay at a particular rate called the half-life. The half-life is the time it takes for half of a group of radioactive atoms to undergo decay.

Radioactive materials exist naturally in the earth's crust. Radioactive materials are also made in nuclear reactors and other nuclear devices. The HEDR Project is studying the potential exposure to people from release of radioactive materials produced in the nuclear facilities at Hanford.

The first three nuclear reactors—B, D, and F—began operating in 1944 and 1945. Chemical separation plants T and B were started up in December 1944 and April 1945, respectively. After World War II ended in 1945, the reactors continued to irradiate uranium fuel and produce plutonium. From 1949 through 1963, six new reactors—H, DR, C, KW, KE, and N—and several new separation plants began operating. In addition to producing plutonium, N Reactor produced steam to generate electricity. This reactor also differed from earlier reactors in that it did not discharge large quantities of radionuclides to the river.

From 1964 through 1988, a reduced need for plutonium led to the eventual closure of all the government production reactors and separations plants, except the PUREX Plant, which continues to be available to process plutonium from a backlog of irradiated fuel.

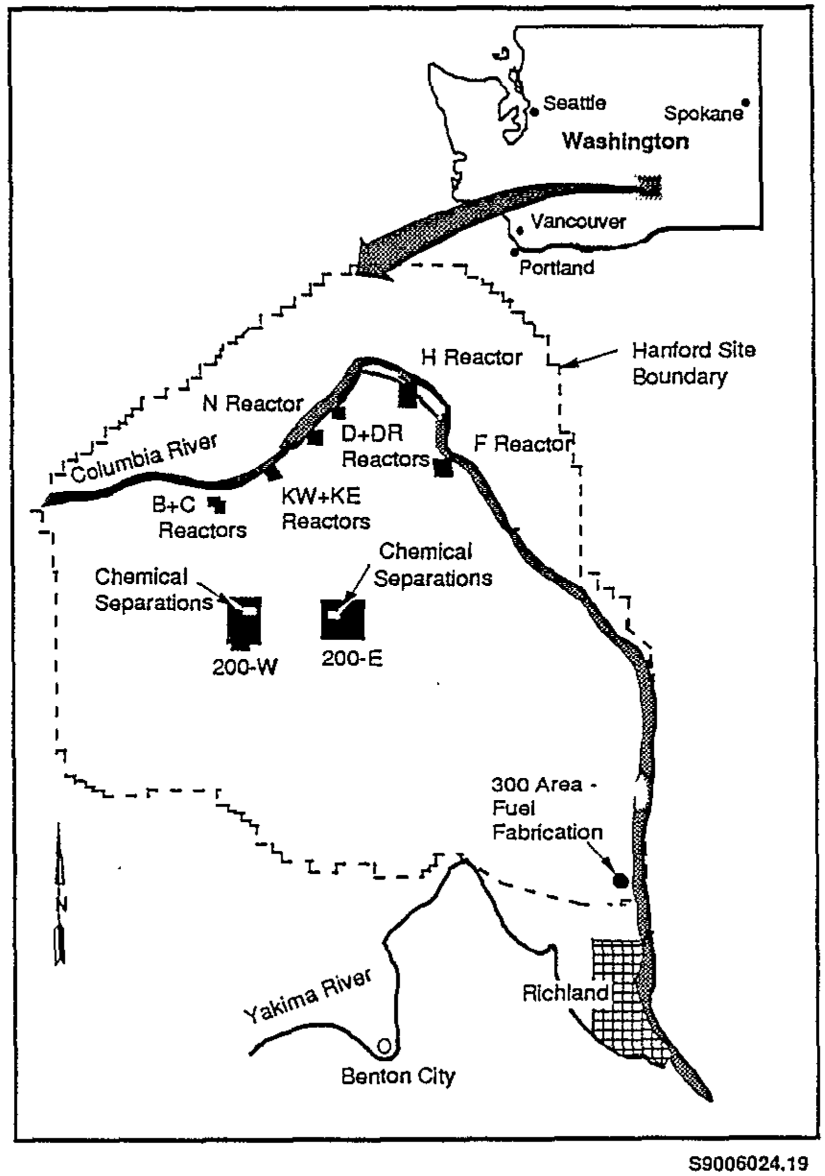
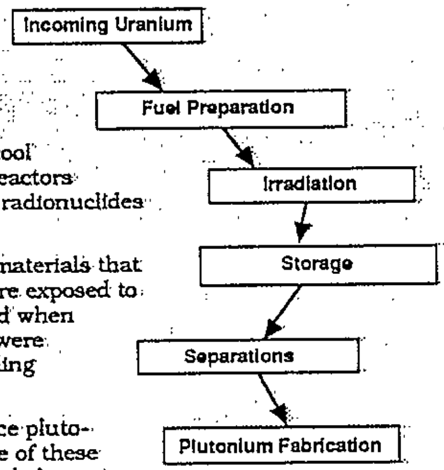


FIGURE 2.1. Location of Hanford Site and Key Operating Facilities

Process operations inside these and related facilities resulted in the release of radionuclides to the air, the Columbia River, and ground disposal facilities.

How and Where Radionuclides Were Produced and Released

The primary mission of the Hanford Site during the Phase I time periods of 1944-1947 and 1964-1966 was to produce plutonium. This mission was accomplished by means of the operations shown in the figure. Uranium was made into fuel elements (uranium fuel encased in metal cylinders) in the Hanford Site's 300 Area, shipped to the reactors to be irradiated (which produced plutonium in the fuel) and then shipped to the 200 Areas where plutonium was chemically extracted from the irradiated fuel. Of primary interest to the HEDR Project were those operations that released radioactive materials to the air and to the Columbia River.



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The irradiation process in the reactors created large amounts of heat. Water from the Columbia River was pumped through the reactors to cool them during operation. This was true for all the Hanford production reactors except N Reactor. N Reactor had a protected cooling system that kept radionuclides out of the cooling water that was released to the Columbia River.

Most of the radionuclides that went into the river were created when materials that occur naturally in the river, or chemicals added to treat the water, were exposed to neutrons in the reactor core. Radioactive materials were also produced when minerals temporarily adhered to the cooling tubes in the reactor and were exposed to the neutrons. These materials were released when the cooling system was cleaned.

When uranium fuel elements were irradiated in the reactors to produce plutonium, hundreds of other radioactive elements were also created. Some of these radionuclides accidentally escaped from occasional ruptures in the fuel elements into the water used to cool the reactors. The cooling water containing these radionuclides was pumped into holding basins to let some of the radioactivity decay. Then the water was released into the Columbia River. These accidental releases were a small fraction of the total amount of radionuclides that were routinely released into the river with cooling water from the reactors.

When irradiated fuel was removed from the reactors, it was stored for several weeks to allow short-lived radionuclides to decay. The fuel was then shipped to the 200 Areas, placed in large vessels, and chemically dissolved to extract plutonium and other radionuclides. During this dissolving process, iodine-131, which is a gas, and some other radionuclides were released from the vessels, routed to tall exhaust stacks, and released to the air.

2.2 Monitoring of Radioactive Materials From Hanford

The release of radioactive materials from Hanford was controlled through several steps beginning with process controls and ending with personnel monitoring (Figure 2.2).

Each of these control measures evolved as experience was gained in control and monitoring technology and in knowledge about the potential for health effects from radiation exposure. Processes were adjusted and timed to result in releases that were considered safe. In the early years of operation, releases and their potential for exposing workers were compared with guidelines adopted from the medical community by Hanford scientists (Wilson 1987). Regulatory standards were not developed until the 1950s.

Emissions monitoring, which began with the startup of Hanford facilities in 1944, consisted of measuring the amounts of radioactive materials vented to the atmosphere and released to soils and to the Columbia River. Measurements of materials released to the river were reliable from the time Hanford facilities started operating. However, the technology to accurately measure atmospheric releases evolved for several years before measurements became reliable. Meanwhile, atmospheric releases were estimated on the basis of process information and estimated filter efficiencies when effluent filters were installed in 1948 (Burger 1989).

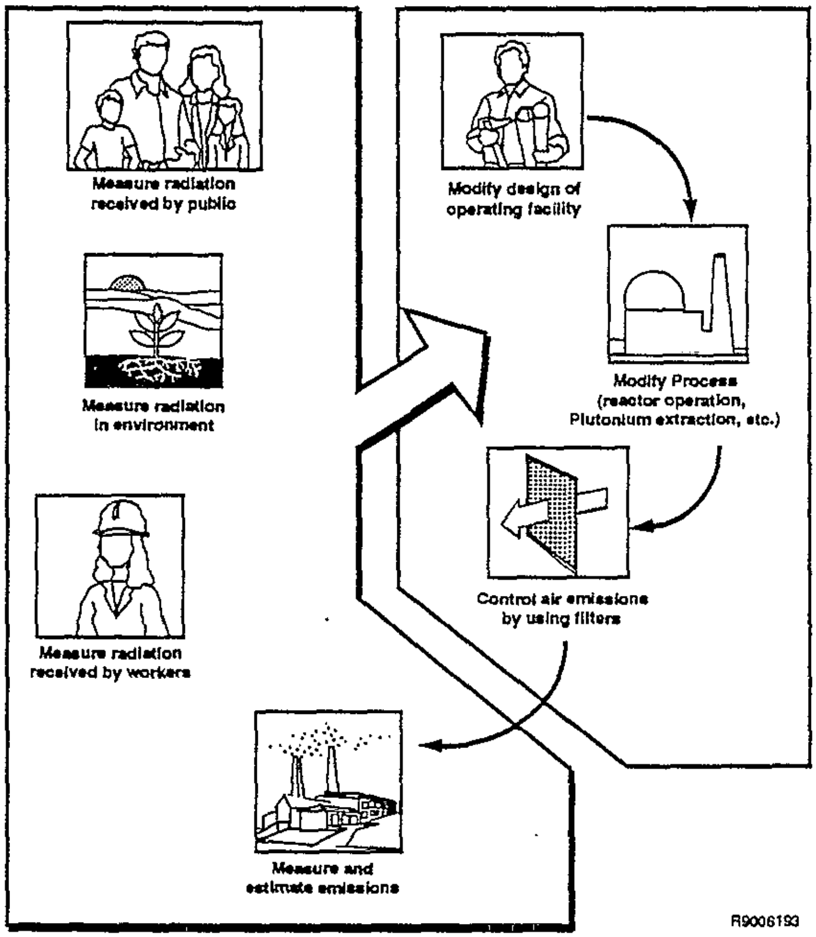

FIGURE 2.2. Methods Used to Control Releases from Hanford Site Facilities

Control of Radioactive Releases

When Hanford facilities first began operating, operators of these facilities controlled releases of radioactive materials to comply with early guidelines. Later, regulatory standards were followed concerning allowable concentrations of radionuclides in the environment and exposure of Hanford workers and the public. Measuring the amounts of radionuclides that have been released, that have traveled into the environment, and that have been absorbed by humans is known as monitoring. To determine whether releases of radioactive materials were within guidelines or standards, scientists monitored radionuclides in emissions, the environment, workers, and later, and to a limited extent, the public.

As time went on, knowledge about potential health effects of exposure to radiation was gained, and the technology for monitoring emissions and radionuclides in the environment and in people improved. Using this improved knowledge and technology, operations were changed to reduce emissions of radionuclides that were known to result in the largest exposures to people.

Emissions Monitoring—Liquid and gas releases of radionuclides were measured periodically or continuously at or near the point of release with various types of automated equipment. This sampling was called emissions monitoring. One objective of monitoring emissions was to estimate the type and amount of radionuclides released to the environment so that releases could be maintained within operating specifications. Emissions monitoring was also used to detect any accidental releases or indications that the process equipment was not working properly.

Environmental Monitoring—Air, river water, drinking water, ground water, soil, vegetation, game birds, game animals, fish, shellfish, milk, and crops are checked periodically to measure in them any radionuclides originating from Hanford. This type of measurement, known as environmental monitoring, is used to determine whether radionuclides released from Hanford to the environment are within regulatory standards. Environmental monitoring also provides a check on the validity of the emissions monitoring.

Personnel Monitoring—Personnel monitoring is the process of measuring radioactivity in Hanford workers. Workers are monitored to determine whether their exposure to radiation is within established standards. Monitoring systems include detectors, called dosimeters, that are worn continuously while in potential radiation areas; the use of hand and foot monitors at points of exit from buildings that might contain radioactive materials; scans of clothing of workers who are preparing to leave areas likely to contain radioactive materials; and whole-body counts to detect possible intake of radionuclides. All these systems provide more checks to determine whether operations are being conducted within specifications, and ultimately, to protect people and the environment.

Whole-Body Counters—Hanford Site workers who might come in contact with radioactive materials that could be ingested or inhaled are periodically monitored with an instrument called a whole-body counter. The instrument scans the entire body to detect radionuclides that might have been inhaled or ingested and that could concentrate in various parts of the body. During the late 1960s and early 1970s, these instruments were also made available to monitor interested members of the public.

Environmental studies, which started before Hanford facilities began operating, consisted of meteorological studies and laboratory evaluations of fish exposed to liquid emissions. Meteorological measurements and observations of atmospheric plume behavior began in 1943 to predict the path and amounts of radioactive materials released to the air. It was determined early in Hanford's history that releases should be confined to meteorological conditions that would reduce the possibility of worker exposures and that would result in maximum dilution by the atmosphere (Operation of Hanford Engineer Works, S Department 1946).

Environmental monitoring was expanded to measurements of radioactivity in the air, ground, vegetation, food, wildlife, Columbia River water, drinking water, sediment, fish, and other aquatic life. It was not until the mid-1950s, however, that the possibility of milk as a pathway for radioactive iodine was recognized

(Parker 1956; Comar et al. 1957). Consequently, milk containing iodine-131, which resulted in radiation exposures of as much as 10 to more than 100 times as high as exposure from breathing iodine-131, was not monitored during the period of highest releases of iodine-131, from 1944 through 1947.

Employees were checked for possible radiation exposure from the time they began working at Hanford (Wilson 1987). External exposure (radiation on workers' bodies or clothing) was measured using devices known as pencil dosimeters and hand and foot counters. Clothing and extremities were scanned with Geiger counters. In addition, to measure radionuclides that may have been absorbed or ingested, a bioassay program, and limited scans of the thyroid glands of specific workers were also begun.

Beginning in 1959, whole-body counts of Hanford workers were also conducted (Wilson 1987). Monitoring of people with whole-body counters off the Hanford Site began in 1965. More than 5,000 schoolchildren in the Tri-Cities area were monitored (Endres et al. 1972). The thyroid scans and whole-body counts of workers and the public are good sources of independent data to compare with the HEDR dose estimates.

Potential radiation doses to the general population near the Hanford Site were reported for the first time in 1957 and have been estimated in annual environmental monitoring reports ever since. Dose calculation methods have evolved and improved over the years as technology has improved. Until 1973, dose estimates were based on measurements of radionuclides in the environment and in foods. After 1973, amounts of radionuclides in the environment decreased to the point where they could no longer be directly measured. Instead, they were estimated based on modeling from measured or estimated releases (Fix 1975). The decrease in radionuclides in the environment resulted from improved control technology, closing of the original reactors, and closing of major chemical separations plants.

3.0 Dose Reconstruction

Dose reconstruction starts by gathering information about contaminants released to the environment and determining how and where they traveled in the atmosphere, soil, ground water and river water. Next, scientists identify the biological paths the contaminants take through food chains to humans. Information is gathered about the number of people that could have been exposed, and their age, sex, food habits, lifestyles, and any other factors that could influence their exposure to contaminants. All these factors are put together to estimate radiation doses. Figure 3.1 shows the dose reconstruction process used by the HEDR Project.

How Radiation Dose Estimates Were Made

Estimating radiation dose from past exposure is somewhat like constructing a huge jigsaw puzzle with most of its pieces scattered around the neighborhood and the rest lost. Scientists searched for and extracted information from historical records. Where past information was missing, scientists estimated it as closely as possible.

Like detectives using clues to reconstruct an event, scientists pieced together information to reconstruct how radiation reached people. They began by estimating the types and amounts of airborne and liquid materials released from Hanford facilities. Next they estimated the amounts of radioactive materials that appeared in air, water, fish, vegetation, and soil. Ways people could have been exposed to radionuclides—such as breathing contaminated air or consuming contaminated food—were identified. These routes of radiation travel are called exposure pathways. Next, information was estimated about the numbers of people who could have been exposed, where they lived, and what they ate and drank. All this information was fed into a complex computer program that calculated the radiation dose estimates.

3.1 Phases

The HEDR Project is being conducted in four phases as shown in Figure 3.2. The objectives of Phase I were to 1) determine whether sufficient historical information could be found or reconstructed to estimate doses, and 2) determine whether a dose reconstruction model could be constructed to provide preliminary, realistic estimates of radiation doses to the public. Achieving these goals required that the study area, time periods, radionuclides, and populations of interest be limited.

Phase II will be a review and testing phase during which Phase I preliminary results will be examined to determine how to improve the accuracy and precision of the final dose estimates to be calculated in Phase IV. Phase II objectives will be reached by identifying the input information most responsible for potential inaccuracies and imprecision in the preliminary dose estimates.

Phases III and IV will be used to refine input data, modify the model, expand areas, extend time periods, and ensure that all key emissions of radioactive materials from Hanford are addressed.

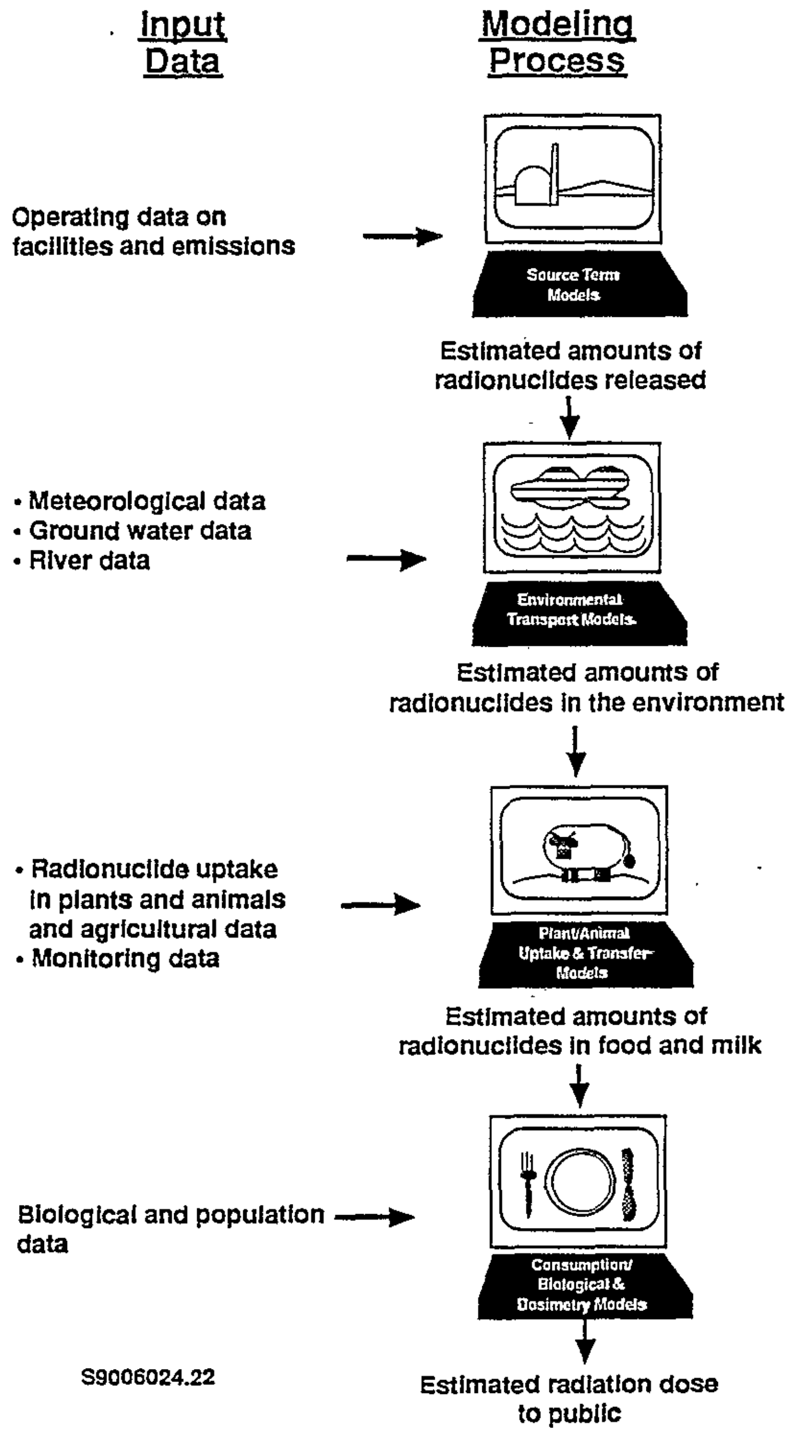

FIGURE 3.1. Dose Reconstruction Process

The final dose estimates generated in Phase IV will be more accurate and precise than the Phase I preliminary estimates as a result of improving the input information and improving the models themselves. Nevertheless, the dose estimates will always remain estimates. They will always include some inaccuracy and imprecision from variability in nature and unavoidable imprecision in input information.

Accuracy and Precision

These terms refer to different ways of characterizing how good, how close, or how certain some estimate is of the true value. For example, consider three ways to describe an estimate of the height of a group of people: 1) as 6 feet; 2) as 5 feet-11 and 1/8 inches; or 3) as something between 5 feet-6 inches and 6 feet-6 inches with a likelihood of 95% that the average value is between these two values. Then say we measure each member of the group and find that the average height is 5 feet-11 and 7/8 inches, and that the heights range from 5 feet-7 inches to 6 feet-3 inches. Estimate number 1 is an *accurate* estimate of the average height of the group, though it is not very precise (exact). Estimate number 2 is a *precise* estimate (to the nearest 1/8 inch), but not as accurate as number 1 (nearly an inch off). Number 3 is a reasonable estimate of the uncertainty in the heights because the estimate contains the average value and the entire range of values.

The approach used in number 3, the use of distributions, gives the most information. The HEDR Project uses distributions as input information to the dose model, and the model calculates distributions as output information. Thus, we obtain not only an estimate of the average values and ranges but also the likelihood of dose estimate amounts of interest. Accuracy is more important than precision during Phase I. Sources of uncertainty in the computer model and its input information will be investigated in later phases to improve the precision of the dose estimates.

PHASE I

Model Development & Testing

- Select limited scope: geographical area, time period, radionuclides, populations
- Find, evaluate, and summarize historical data
- Develop conceptual & mathematical models and incorporate uncertainty
- Apply models/data to limited scope to test the model

PHASE II

Sensitivity/Uncertainty Analysis

- Evaluate Phase I model results
- Identify key parameters for dose calculation via sensitivity analyses
- Determine feasibility/value of reducing uncertainty in parameters
- Propose to expand scope (geographic area, time period, populations) in context of established dose threshold
- Recommend action to reduce uncertainties and recommend changes in conceptual/math models

PHASE III

Expansion and Refining

- Expand scope as warranted by Phase II work
- Reduce uncertainty in key parameters per Phase II recommendations
- Modify models per Phase II recommendations

PHASE IV

Dose Calculation

- Calculate final estimated doses

FIGURE 3.2. HEDR Project Phases

Reducing Uncertainty in the Dose Estimates

Scientists used a simplified computer model in Phase I to get preliminary estimates early in the project. The computerized approach was developed and tested with great care to make it as error-free as possible. Now scientists will investigate the model to see where it can be changed to obtain more accurate doses, such as by putting in additional information when estimates are made.

Much of the historical data that goes into the computer model contains gaps. Some historical records are incomplete, missing, or not sufficiently detailed. Data gaps like these mean that radiation dose estimates can never be totally certain, even the final ones at the end of the project. However, scientists estimate missing or incomplete data as closely as possible, and use it in the computer model that estimates doses.

The final dose estimates will be more certain—or accurate—than the preliminary ones are. This is because scientists will have reduced as many uncertainties as possible in the computer model and data that go into it. Also, more accurate or detailed historical information will be reconstructed for some aspects of the study, which will result in more specific input for use with the computer.

3.2 How HEDR Dose Estimates are Depicted

Until recently, dose assessment efforts such as the HEDR Project used an approach that resulted in a single number to represent a best estimate of radiation received by people. For example, as in Figure 3.3a, radiation doses estimated for residents near a nuclear facility might have been given as 1 millirem to an "average" or "typical" individual during a particular year. (A millirem is one-thousandth of a rem.) Such a single-number estimate provides no information about the range of doses that might actually occur, no hint about the accuracy or precision of the estimate, and no indication of whether most people received a dose near 1 millirem or if doses were equally dispersed over a broad range from, for example, 0.01 to 10 millirem.

Sometimes a range of dose estimates is provided, as shown in Figure 3.3b. By itself, the range does not provide information about whether most doses are at the low end, the middle, or the high end of the range. An improvement on this approach is to have the average value and the range provided, such as in Figure 3.3c.

Distribution

A distribution is a grouping of measurements—such as measurements of heights, weights, or incomes—according to how common, frequent, or likely they are. In dose reconstruction, distributions show the proportion or percent of a population that receives doses greater than a value selected from the dose range. These distributions can also be used to determine the fraction of a population that received amounts of radiation within any specified range.

Additional information can be provided by indicating the likelihood, or probability, of certain dose values, such as shown in Figure 3.3d. Finally, by depicting the information as in Figure 3.3e, information about the range, the median (middle), and the percent of doses greater than any value can be seen.

Distributions can provide an estimate of a middle (median) value, as shown by moving in the direction of the arrows in Figure 3.4a. Distributions also provide information about the percent of doses that are greater than an amount selected on the dose axis. This is done by moving horizontally to the right along the dose axis in Figure 3.4b (see dotted arrows) to 1, 10, or 100, then moving vertically from these values to a point where the vertical lines intersect the curving line. Then, moving left horizontally to the vertical axis shows that 85% of the people are likely to have received doses greater than 1, 25% greater than 10, and 5% greater than 100.

For illustration only—not actual dose estimates

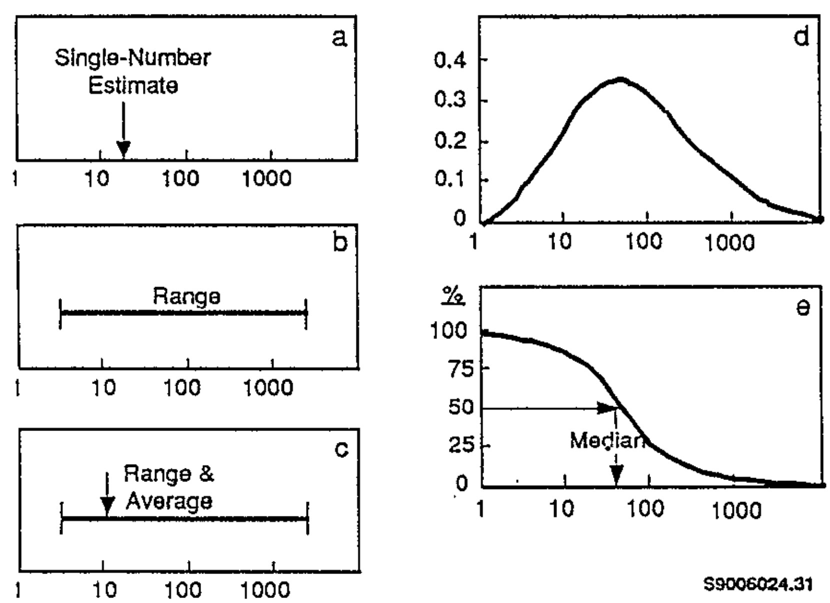

FIGURE 3.3. Options for Ways to Describe Doses

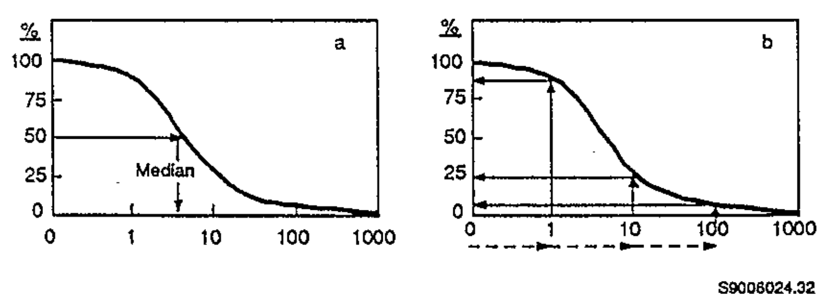

FIGURE 3.4. Information Given in Hypothetical Dose Estimate Distribution

For the HEDR Project, scientists felt it was important to consider differences in radiation doses that would result from differences in age, sex, lifestyle, food habits, geographical location, agricultural production, month, season, year, and other factors. To accomplish this objective, input information to the HEDR Project model consists of distributions instead of single-number estimates. For example, instead of using one number to represent the amount of milk all people in the Phase I study area drank per day, the HEDR Project uses a distribution of amounts of milk people could have drunk. This approach accounts for variability—that actual milk consumption can range from none to more than a quart a day, and that some amounts are more likely than others. It also accounts for uncertainty from lack of knowledge—it is unlikely that a person could remember exactly how much milk he or she drank 45 years ago. The use of distributions enables the preliminary dose estimates to reflect differences in milk consumption in the population.

In Phase II, scientists will work to reduce uncertainty as much as possible by concentrating on improving input information associated with the largest area of uncertainty in the output information.

Uncertainty

Uncertainty in the dose estimates can be caused by several factors. One is uncertainty resulting from incomplete information such as not being able to measure all the food people actually ate. Another source is the possibility of errors made in past measurements of radiation in emissions, the environment, or people. Natural variations also contribute to uncertainty in much of the input information to the dose model. Examples of these variations include differences among individuals in age, sex, lifestyle, and geographic location; differences among dairy cows in the amounts of contaminated pasture grass they ate; and differences in milk production of individual cows during the year.

If perfect knowledge of these variations were available, and if this knowledge could be incorporated in the modeling process, then natural variability would not be contributing to uncertainty. However, because of the impossibility of collecting every piece of this information, scientists estimate the variability in input information. These uncertainties are reflected in the resulting dose estimate distributions.

3.3 Quality Assurance

In a project the size and complexity of the HEDR Project, many opportunities for errors exist. Mistakes could be made in input selection, transcription of raw data to a specific input format, formulas used to calculate results, computer codes developed to make calculations, and depiction and interpretation of results. The HEDR Project uses a strict quality assurance (QA) program that helps to reduce the chances of making errors and improves the chances for detecting and correcting them. The QA program helps ensure that results will be scientifically accurate and defendable, that the entire process is documented, and that the documentation is retrievable.

As depicted in Figure 3.5, the QA process begins with planning. Work plans and QA plans that specify technical and administrative procedures are developed and training is conducted. The process continues with documentation and checking of calculations, software development and application, data evaluation, and independent verification of the traceability and retrievability of project records.

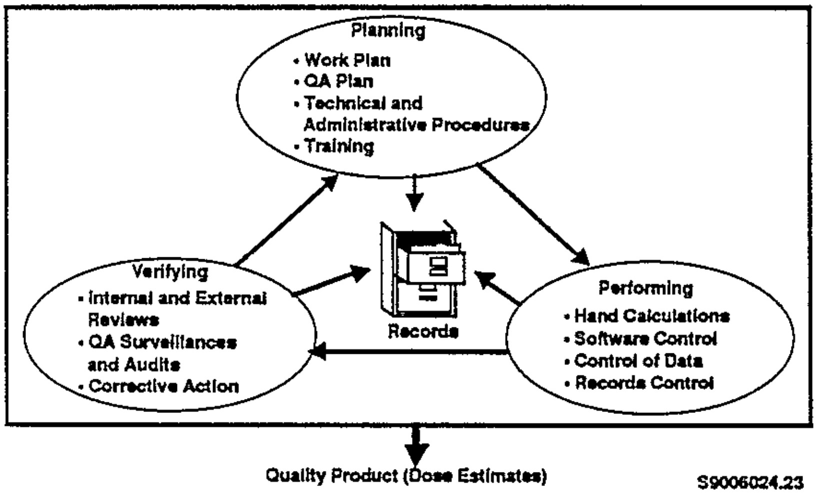

FIGURE 3.5. Quality Assurance Process

During this iterative process, continuous surveillance and periodic audits occur to ensure compliance with the established procedures. In Phase I, QA surveillances were conducted on various computer codes and software, databases, and estimated data as summarized below:

- computer code used to estimate radionuclides released from Hanford facilities
- computer code used to calculate radionuclide transport in the atmosphere
- computer code used to estimate dose from iodine-131 to an infant's thyroid
- computer code used to estimate dose to adults who ate Columbia River fish
- computer software used to evaluate the correction factor for radionuclides in vegetation
- population database

- database containing measurements of radionuclides in fish
- calculated radionuclide amounts in the Columbia River
- estimates of feed intake by cows and milk production/ distribution.

In addition, three audits were conducted of Phase I work—two on administrative controls (i.e., staff training, records, reviews, etc.) and one on data traceability of reported results.

4.0 Air Exposure Pathway

Phase I consists of two parts: 1) reconstructing potential radiation doses from the release of radioactive materials into the atmosphere, and 2) reconstructing potential doses from the release of radioactive materials to the Columbia River and to soils on the Hanford Site. This chapter covers the air exposure pathway only (Figure 4.1). Chapter 5.0 discusses the Columbia River exposure pathway.

4.1 Approach

This section discusses the selection of the geographic area, time periods, radionuclides, and exposure pathways that were selected for Phase I dose estimation for airborne radionuclides.

Area

The Phase I study area for the air pathway covers the 10 counties nearest the Hanford Site (Figure 4.2). This area was selected to encompass populations nearest the releases and therefore most likely to have been in the path of the highest concentrations of radioactive materials transported by the atmosphere from Hanford facilities. The Phase I study area also includes areas that were usually upwind and therefore were least likely to be in the path of high concentrations of radioactive materials originating at Hanford. This variety provided the ability to determine whether HEDR Project models could deal successfully with a wide range of doses. Finally, the area was purposely limited to counties near Hanford as part of the objective of Phase I to emphasize testing the feasibility of reconstructing doses rather than encompassing all areas that might have been exposed to Hanford releases.

Time Period

As illustrated in Figure 4.3, iodine-131 releases were highest in the early years of Hanford operation. It is estimated that the period 1944-1947 accounts for more than 90% of iodine-131 released since startup of the facilities (Anderson 1974). The Phase I time period was therefore selected to include the highest estimated releases and highest probable doses from iodine-131. It is important to recognize that iodine-131 disappears within a few months of its release because it decays rapidly (half decays every 8 days; therefore, less than 1 millionth remains after 160 days of its release).

Iodine-131 - Its Origins, Pathways, and Potential Effects

The principal radionuclide of interest during Phase I is radioactive iodine, called iodine-131. Large amounts of iodine-131 were released. Rough estimates made early in the project showed this material would account for most of the radiation doses people could have received from Hanford. This radionuclide is one of hundreds that are produced when uranium fuel is put in a reactor to make plutonium. Iodine-131 is relatively short-lived, that is, every 8 days half of the amount that existed 8 days earlier will have decayed. As a result, after about 80 days, less than one-thousandth remains; after 160 days, or 20 "half-lives," less than one-millionth of the original amount remains.

Irradiated fuel was removed from reactors, stored for several weeks, and then dissolved in acid to remove plutonium. During this dissolving process, remaining iodine-131 was released to the air. During the Phase I period of 1944-1947, iodine-131 was discharged from tall "stacks" (like smokestacks) to the environment. Later, filters were used to trap most of this iodine. Also, irradiated fuel was stored longer before it was dissolved in the chemical separations plants until little, if any, iodine-131 remained.

Once the iodine-131 was released to the air, it traveled with the winds. As the iodine-131 traveled over land, some fell onto vegetation and the ground. During the growing season, iodine that had deposited on pasture used by dairy cows would have been eaten by the cows. Considerable amounts of iodine-131 in pasture grass eaten by cows would have shown up in the cows' milk, which people could have drunk. Much of the radioactive iodine-131 consumed by people would go to the thyroid gland, an organ that needs iodine to function. About half of the iodine-131 absorbed by the thyroid gland during a day remains after 6 days. Part of the loss of iodine-131 results from radioactive decay, and part of the loss is from biological processes that remove iodine.

While iodine-131 is in the thyroid gland, it irradiates surrounding tissue. The amount of radiation, or energy, absorbed by the thyroid gland and surrounding tissues is calculated as a radiation dose.

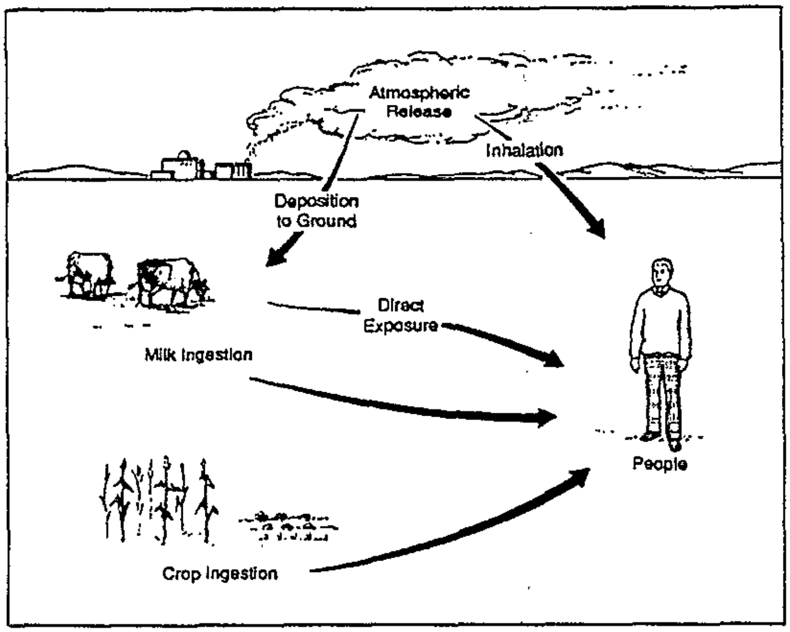

FIGURE 4.1. Air Exposure Pathways Used for Dose Estimation

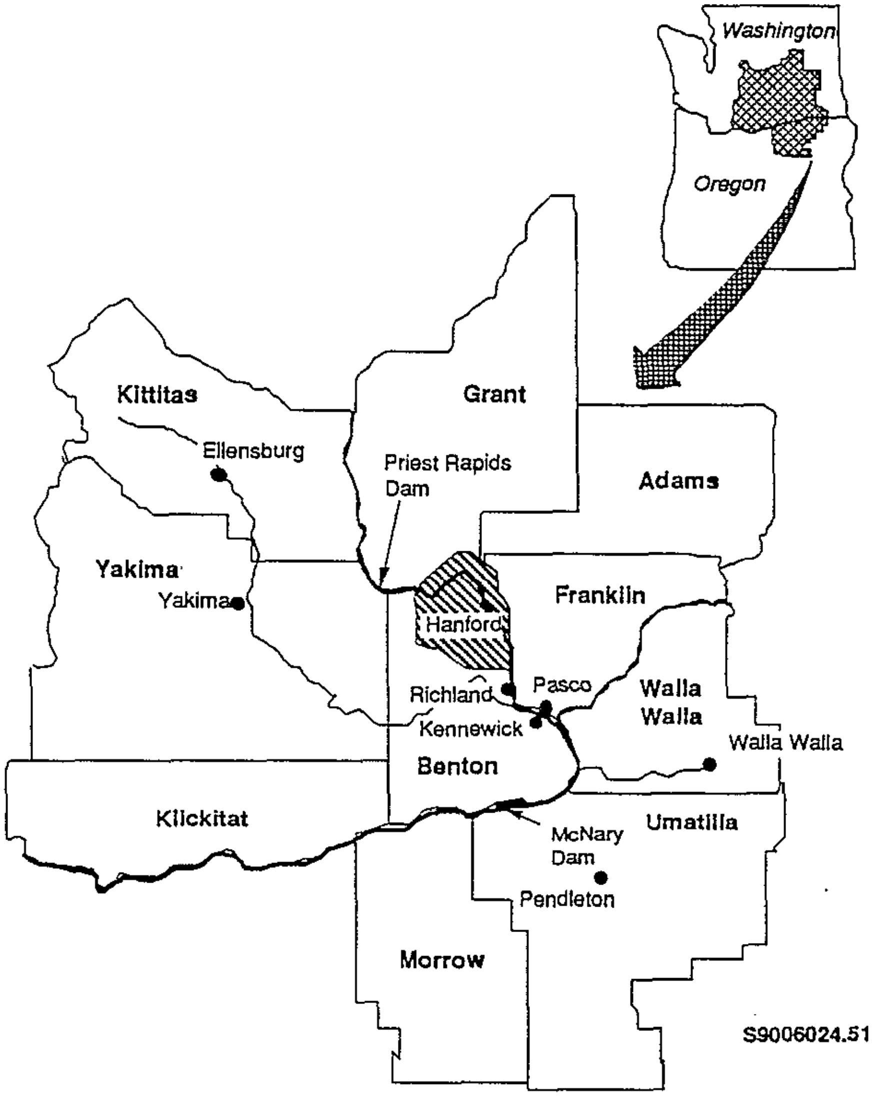

FIGURE 4.2. Phase I Study Area - Air Exposure Pathway

Measured Radiation

The curie is used to express the amount of a radioactive material present. It measures the number of atoms of a particular radioactive element that decay each second. One curie is 37 billion atoms undergoing radioactive decay each second. The millicurie (one 1/1000 of a curie or 37 million decays per second) and the microcurie (37 thousand decays per second) are also commonly used to express the amount of a radioactive material present.

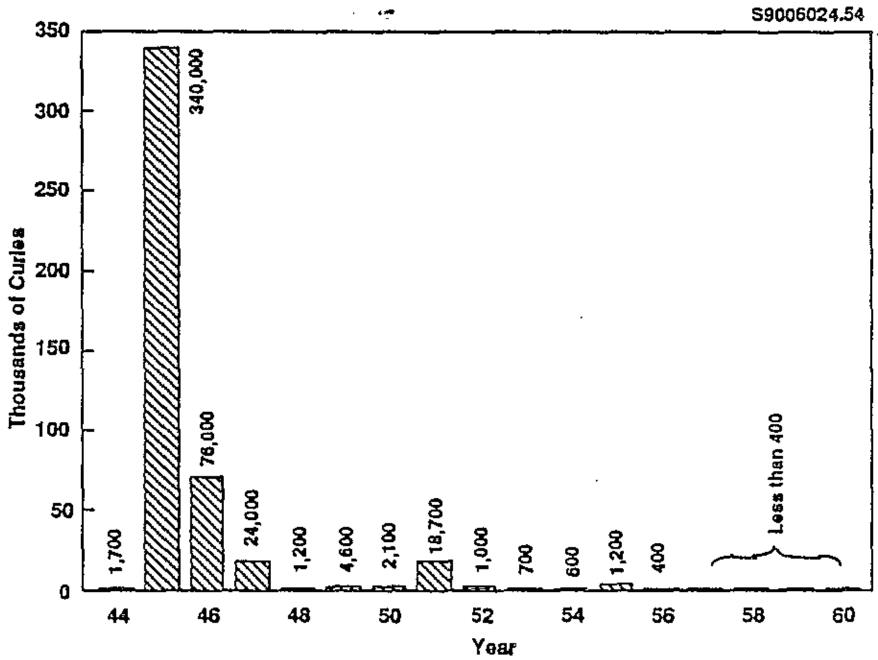

FIGURE 4.3. Estimated Releases of Iodine-131 from Separations Plants

Radionuclides

Phase I focused on iodine-131 because studies showed that it accounted for most of the dose from the air exposure pathway (Ruttenber and Mooney 1987; Napier 1990) (Figure 4.4). Other radionuclides and time periods will be addressed in later phases.

Exposure Pathways

Atmospheric releases of iodine-131 can result in radiation exposures through several pathways (Figure 4.1). Of these pathways, drinking fresh milk containing iodine-131 that was consumed by dairy cows grazing on contaminated pasture results in the highest doses. Other, less important, pathways are via eating contaminated vegetables, fruit, or eggs; drinking contaminated water; inhaling iodine-131 in air; being immersed in or near a cloud of iodine-131; and being exposed to radiation from surfaces on which the iodine-131 deposited. Because of the importance of the milk pathway, a significant effort in estimating doses from air exposure went into detailed reconstruction of the dairy industry as it operated in the middle to late 1940s.

The pathway of radionuclides being carried by irrigation water to crops that people eat will be investigated in later phases of the project.

4.2 Input Information

This section describes the input information used in the model to estimate doses from the air exposure pathway. A variety of data from on the Hanford Site and off the site was used.

Onsite Data

Data on the Hanford Site for estimating doses for residents living in the study area from 1944-1947 include calculated emissions, meteorological information, and Hanford employee monitoring data.

Releases of iodine-131 to the atmosphere occurred primarily from the exhaust stacks of chemical processing plants (T and B Plants) in the 200 Areas (Figure 4.5). Details concerning the processes that resulted in the release of iodine-131 can be found in Burger (1989). Several years elapsed before technology to monitor iodine-131 releases produced reliable data. In the interim, engineering calculations were used to estimate the amount of iodine in the irradiated fuel that was released to the atmosphere during dissolving operations (Morgan 1990). HEDR Project staff reconstructed iodine releases by searching for historical records of plant operations and estimating releases by means of engineering calculations. Fortunately, enough records covering plant operations during the Phase I study period were still available.

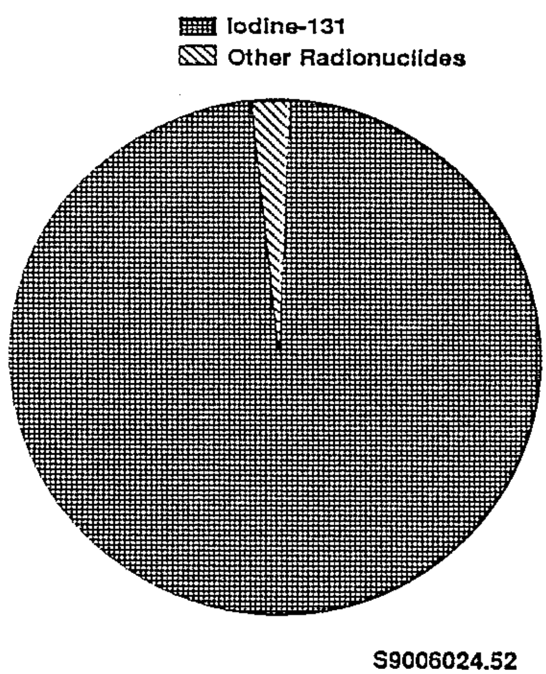

FIGURE 4.4. Radionuclide Fractional Contribution to Dose From Air Exposure Pathway, 1944-1947

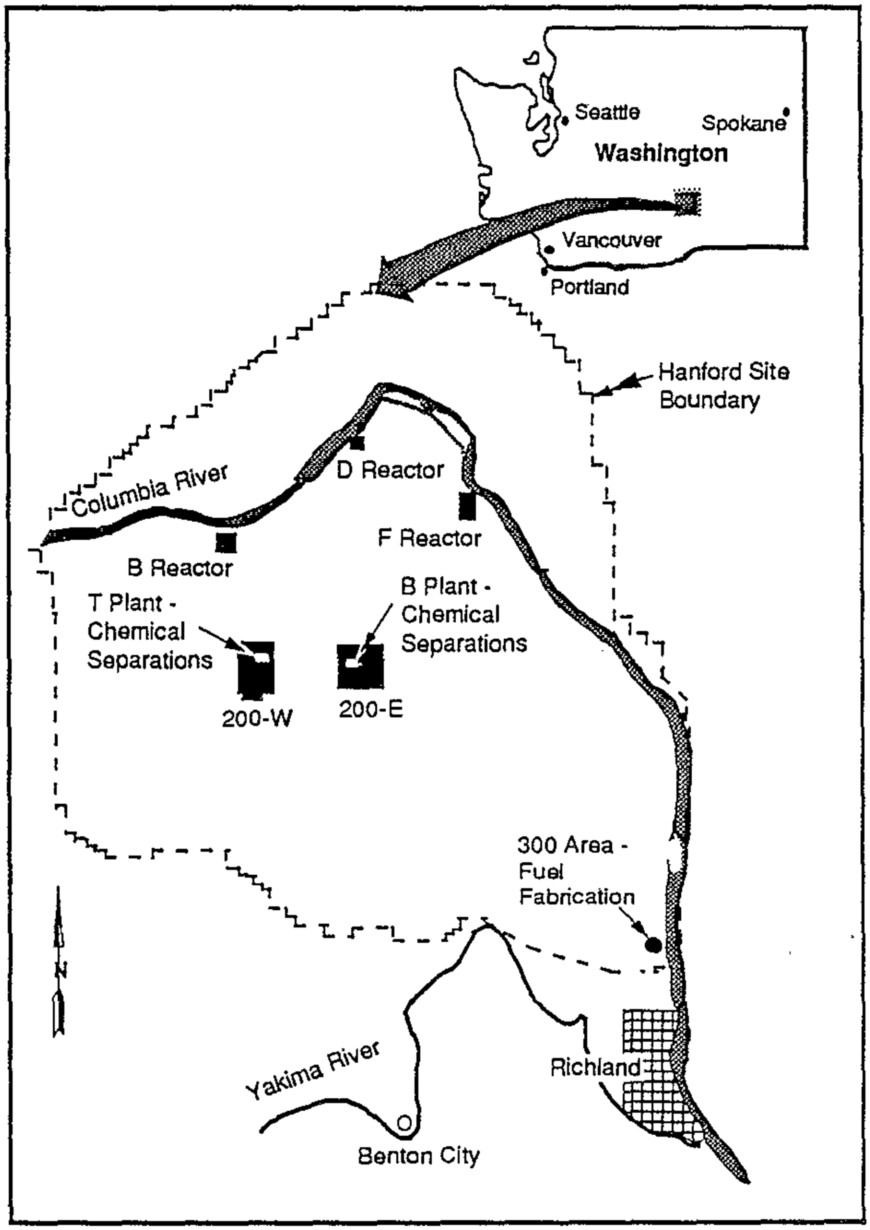

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FIGURE 4.5. Hanford Site, 1944-1947

Estimates of iodine-131 released from the chemical separations plants each month beginning in December 1944 through December 1947 are shown in Figure 4.6. The shaded area shows the uncertainty in the ranges of estimates of the amount of iodine that might have been released from the dissolving vessels to the atmosphere.

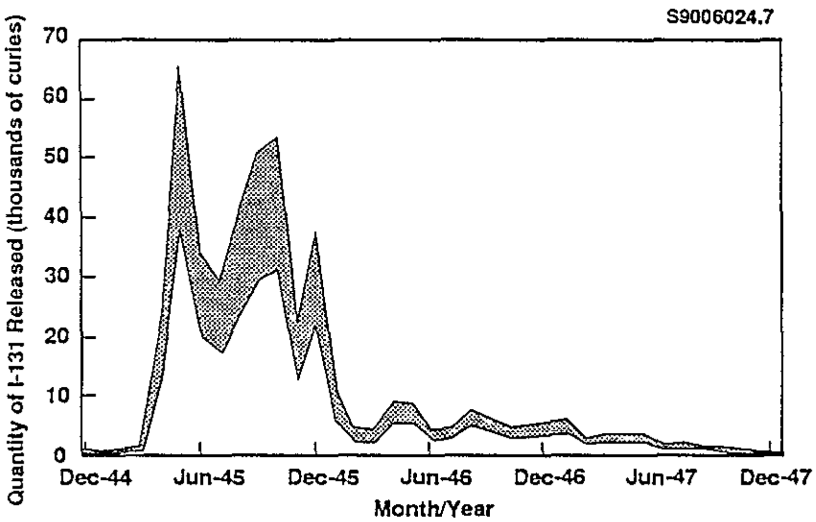


FIGURE 4.6. Estimated Releases of Iodine-131 from Separations Plants

A meteorological monitoring program was begun at the Hanford Site more than a year before plant startup. Hourly temperature, wind speed, and wind direction data were collected at the Hanford Meteorology Station between the processing areas (Figure 4.7). Additional wind data were collected at other locations on and near the Hanford Site and are available for recent years. Figure 4.8 shows the location of the Hanford Meteorology Station and the supplementary wind stations in the Hanford Telemetry System. The supplementary wind data are not available for the 1944-1947 period.

Radiation exposure of onsite personnel was monitored in several ways as discussed in Chapter 2.0. Of importance to Phase I are nearly 8,000 records of thyroid checks. These were measurements of radiation emitted from the thyroid gland that were taken with hand-held monitoring instruments. People who worked in areas where they might have been exposed to iodine-131 were monitored. This included workers such as process canyon crane operators and personnel stationed at downwind security checkpoints. Up to 150 of these workers were monitored each week, but individuals were not monitored according to a specific schedule.

These thyroid checks provide an independent estimate of exposures of adult Tri-Cities residents to iodine-131 while at home and at work. Because exposures from these two sources cannot be separated, the use of these data is limited. However, workers spent about three-fourths of their time off work, and therefore off the Hanford Site. They were therefore exposed to the same amounts of iodine-131 during non-working hours as were Tri-Cities residents who did not work at Hanford. Some of the workers also drank the same milk as Tri-Cities residents.

Offsite Data

Information from off the Hanford Site used as input for Phase I dose estimation includes meteorological, demographic, agricultural, milk production, and milk distribution data; details concerning dairy cow feeding practices; and lifestyle and food consumption information.

In addition to onsite meteorological data, meteorological data available from National Weather Service (Weather Bureau) stations in eastern Washington, northeastern Oregon, and northwestern Idaho were used in estimating the iodine-131 concentrations in the 10 counties around the Hanford Site. Computerized data for the period 1944-1947 were not available from these stations in time to be included in the Phase I calculations. However, data were available for more recent years. As a result, the Phase I calculations were based on data from 1983 through 1987. Preliminary comparisons of the two data sets indicate that they are similar.

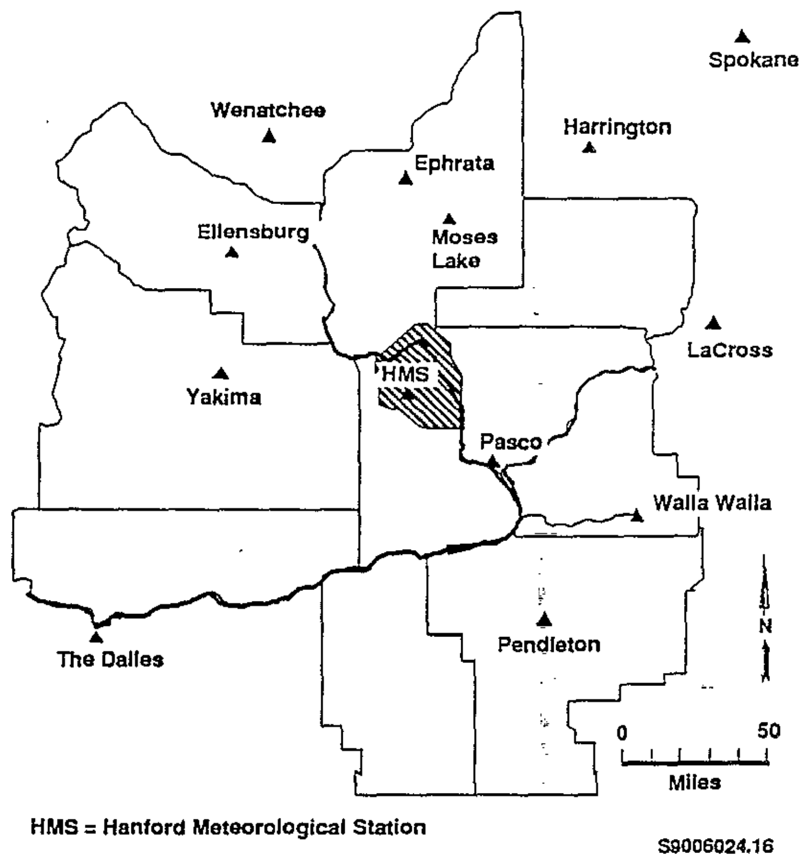


FIGURE 4.7. Meteorological Station Locations, 1944-1947

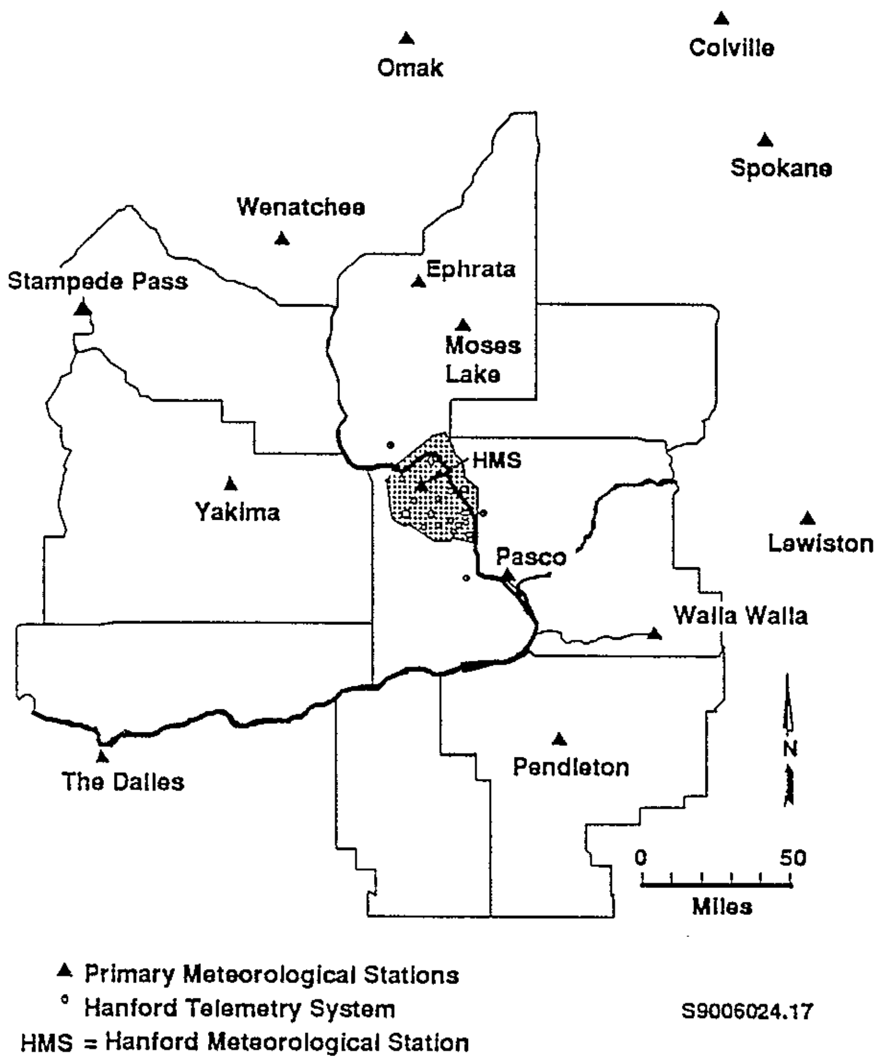


FIGURE 4.8. Meteorological Station Locations, 1983-1987

The 5-year period from 1983 through 1987 was selected because computerized data were readily available from the National Weather Service stations and from the stations in the Hanford Telemetry System. Thus, even though 1983-1987 meteorological data were used instead of 1944-1947 data, this approach provided some benefits. The 1983-1987 data had better definition of radionuclide concentration patterns because the data came from more meteorological stations.

In the Phase I calculations, atmospheric concentration patterns were computed for each month during the 5-year period using wind and atmospheric stability data observed at 3-hour intervals. For dose estimation, typical patterns were computed for each calendar month from the individual patterns. The accuracy of the estimates was checked by comparing them with monitoring data. Initial comparisons of estimated amounts of iodine-131 in sagebrush with amounts measured in sagebrush in 1945-1946 indicate that the Phase I calculations provide reasonable estimates of the actual concentrations in the 1944-1947 time period. Phase II will fully evaluate the effect of using data from the 1983-1987 period on the dose estimates. Differences in data available for the two periods will also be investigated.

Reconstructing the Population

Information about the population is needed to estimate doses from past operations at Hanford. Scientists needed to know the number of people, their locations at different time periods, their ages, and whether they lived in urban or rural areas. This kind of information is available from the U.S. Census, but census information is only collected every 10 years. Population characteristics changed very rapidly around Hanford, particularly during the late 1940s when 50,000 to 60,000 people came to the area to help construct and operate the facilities. Scientists working on the project were able to make good estimates of the population characteristics using information such as birth and death records, school enrollment figures, automobile registrations, and employment records from Hanford. This information was used with 1940 and 1950 census data to describe the population near Hanford during the times of largest releases of iodine-131.

Knowing where people lived, how many there were, and their ages and sexes is critical for estimating doses to populations. Considerable effort went into estimating these values because of the rapid changes that characterized the war and postwar period around Hanford. Typical census data provided estimates for 1940 and 1950, but provided little information about the rapid changes that occurred in Richland, for example, where the population rose from a few hundred to more than 20,000 by 1947 (Figure 4.9).

Reconstructing the Milk System

To estimate the radiation doses people could have received from Hanford radiation, scientists needed to reconstruct the milk production and distribution system near the Hanford Site in the late 1940s. Information was needed on where the milk was produced, where milk sold in stores came from, and where the feed was grown that was eaten by the cows that produced the milk. Very few records remain from the dairy industry during this time. Project scientists interviewed dairy farmers, employees of dairies operating during this time, agricultural extension agents, and dairy industry specialists from universities. Putting together information from all these sources, the dairy system from the 1940s was reconstructed.

Milk in the Tri-Cities came from as near as the Pasco/Kennewick area and as far as the predominately upwind Yakima Valley. As a consequence, radiation doses to Tri-Cities residents from drinking milk vary considerably, as will be shown in the following sections. Dose estimates depend greatly on knowing where dairy cows grazed, where cow feed originated, when cows were put on pasture, how much and what type of supplementary feed was provided, where milk was pooled and processed, and where it was distributed. A significant effort by the HEDR Project, and, incidentally, a contribution to understanding regional history, was reconstructing the dairy industry in and near the 10-county Phase I study area. Milk production and distribution information was gathered through the use of U.S. Census of Agriculture data, Washington State Dairy Products Commission Statistics, interviews with retired dairy industry employees, and information from dairy industry experts.

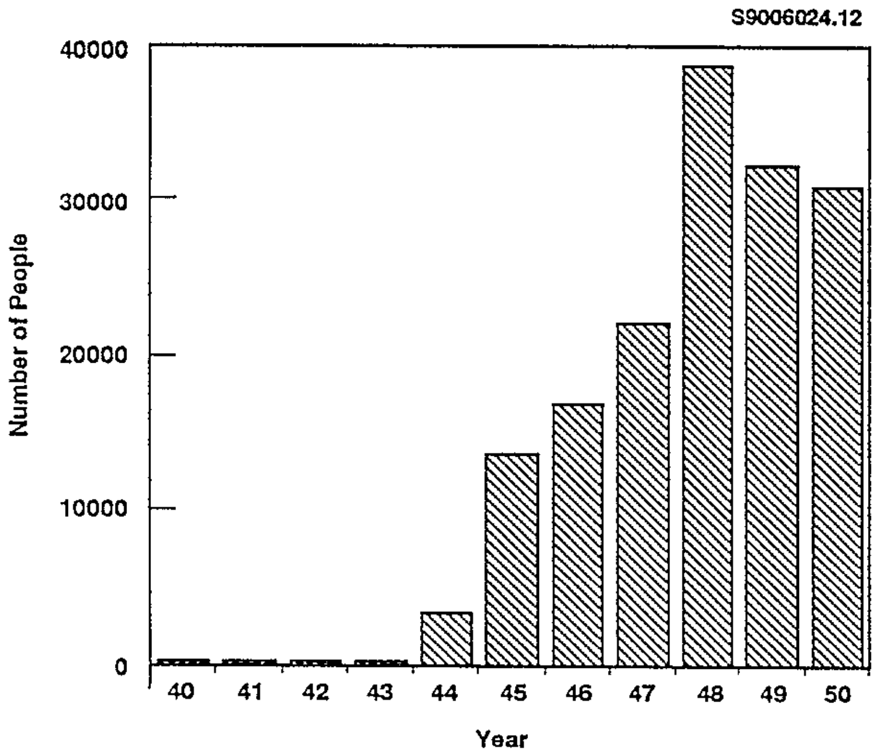


FIGURE 4.9. Number of Richland Area Residents Over Time (Beck et al. 1990)

Once estimates of iodine concentrations in foods have been calculated, the major remaining determinant is knowing what and how much of various foods people ate. National and regional statistics on food consumption were used in the Phase I effort for the general population. The possibility of obtaining more specific information, such as by interviewing residents, was considered but not attempted in Phase I. It is unlikely that asking people to recall what and how much they and their children ate 40 to 45 years ago would provide reliable data. However, a decision about whether to conduct such interviews will be made in later phases of the project.

4.3 Output Information

Two types of key output information from the Phase I model are 1) concentrations of iodine-131 in air, on vegetation (sagebrush or pasture grass) and agricultural products, and in milk; and 2) estimated radiation doses to the thyroid from exposure to this iodine. Patterns of iodine-131 in the air and on vegetation are depicted in Figures 4.10 and 4.11. Examples are provided for winter and summer conditions to illustrate how wind direction and other meteorological conditions vary with time of year and therefore result in different concentration patterns. The summer concentrations of iodine-131 in vegetation provide an indicator of iodine-131 concentrations in pasture grass. Iodine-131 concentrations in pasture grass are used for calculating doses from the milk pathway.

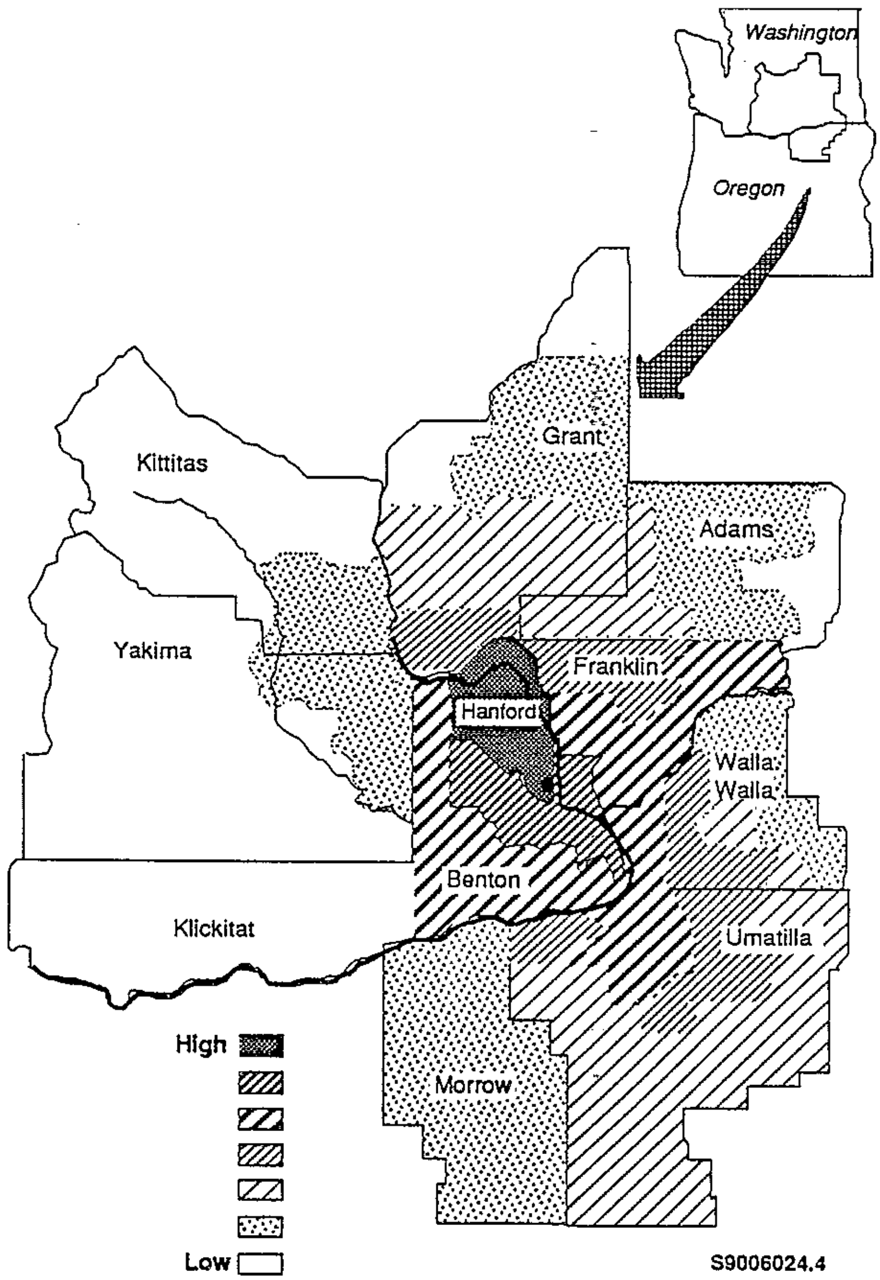


FIGURE 4.10. Patterns of Iodine-131 in Air and on Vegetation, Winter 1945

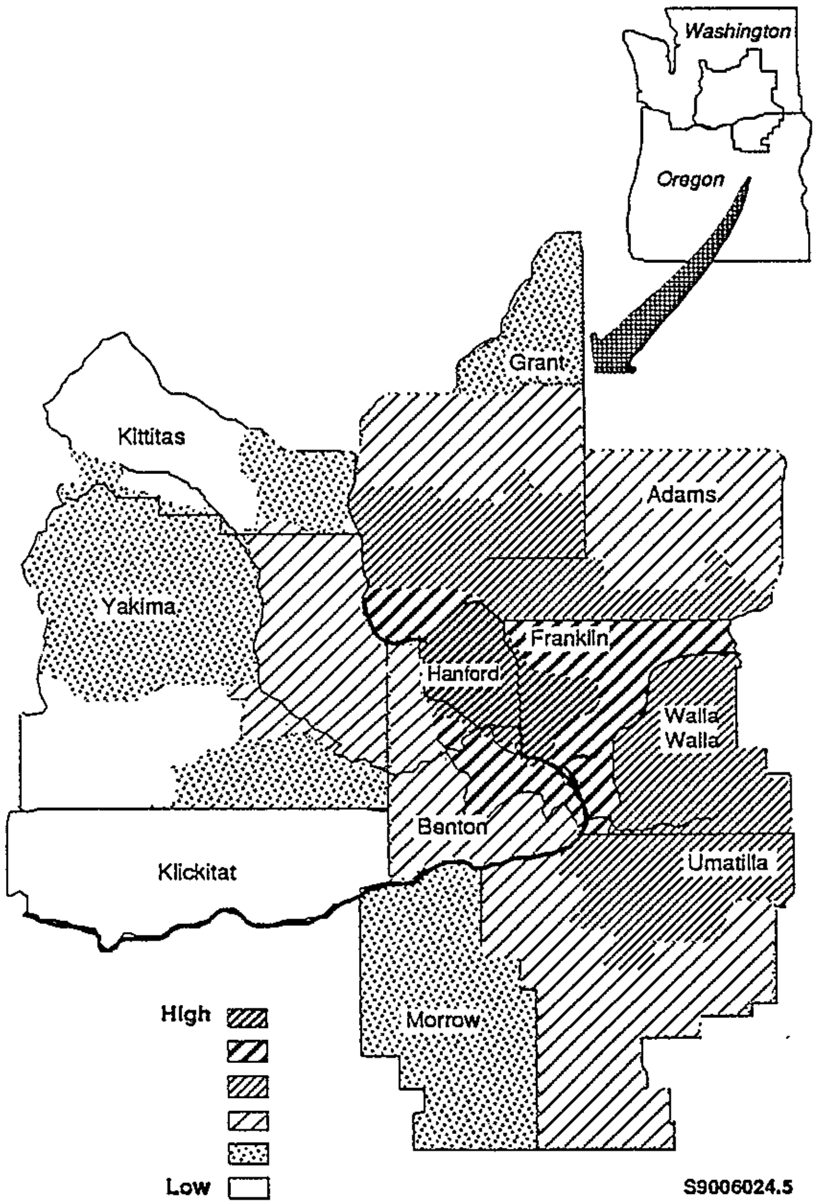


FIGURE 4.11. Patterns of Iodine-131 in Air and on Vegetation, Summer 1945

Sampling

Sampling consists of collecting a specified amount of air, river water, drinking water, soil, food product, or other items from specific locations at specific times. The samples are then analyzed to measure several kinds of radionuclides in them. These analyses are then used to estimate the amounts of radionuclides that are in the environment. The estimation process includes assessing how representative the samples are of the areas and time periods that they represent. For example, if 10 samples of sagebrush were collected at a specific road junction near Hanford on June 15, 1946, how similar are these samples to other sagebrush nearby on the same day or 3 days earlier? These judgments involve estimates of uncertainty. The estimates, in turn, were used to determine whether amounts of radionuclides in the environment were within acceptable levels or if plant operations would have to be altered to reduce releases.

Radionuclide measurements from several kinds of past sampling are used in the HEDR Project. Among these are measurements of iodine-131 in sagebrush from 1945-1947 and measurements of several radionuclides in river water, drinking water, and fish at several locations in the Columbia River downstream of Hanford from 1964-1966. Past estimates of amounts of iodine-131 on sagebrush that were based on sampling were compared with estimates of amounts of iodine-131 based on computer models developed by the HEDR Project. These comparisons help indicate how well the computer models estimate radionuclide amounts and how representative the past sampling was of larger, unsampled areas.

As mentioned, amounts of iodine-131 on vegetation were calculated on the basis of HEDR Project-calculated estimates of iodine-131 released and on meteorological data from the period 1983-1987. Radionuclide concentrations in vegetation were also measured at some offsite locations from 1945 to 1947 and provide a check on how well the HEDR model reconstructs these concentrations. A comparison of measured and calculated amounts for Richland and Pasco is illustrated in Figure 4.12. This comparison shows that the HEDR model generates amounts of iodine-131 on vegetation that are similar to measured concentrations in the downwind areas with highest historical offsite concentrations.

The final output of the HEDR Project Phase I model consists of dose distributions for hundreds of categories of "reference individuals" that differ by location, age, lifestyle, and milk supply. These distributions are available for each of 36 months beginning with January 1945 and ending with December 1947. These distributions have been combined into 13 sets for this summary report, as shown in Section 4.4.

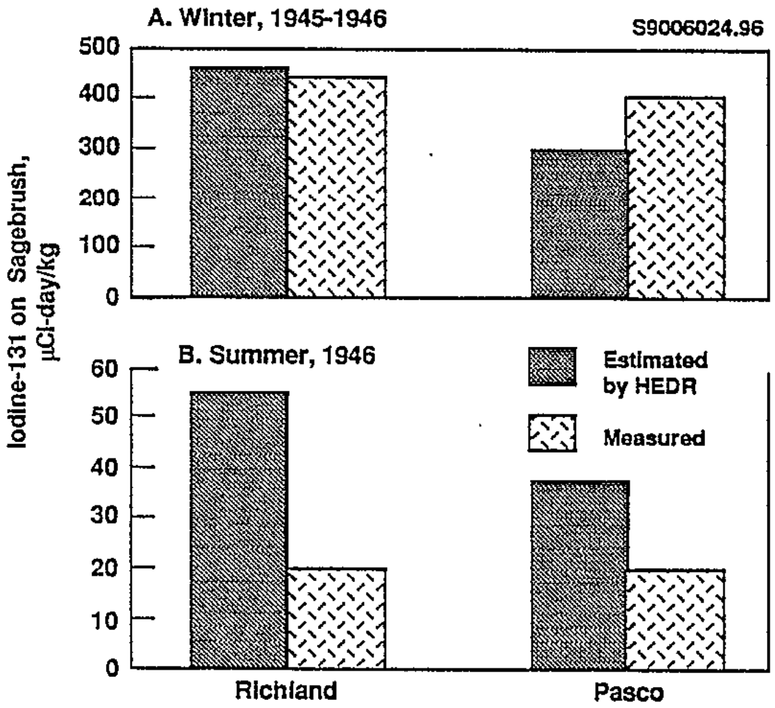


FIGURE 4.12. Comparison of Calculated and Measured Concentrations of Iodine-131 on Sagebrush, 1945-1946 (median values)

4.4 Preliminary Dose Estimates from the Air Exposure Pathway

The factors that had the most effect on the dose estimates are described in this section. The preliminary dose estimates are provided. A guide is also included to help residents of the 10-county area from 1944-1947 to estimate a range of doses that people most like them could have received.

Overview

The final output information of the Phase I model consists of estimated dose distributions for populations and for reference individuals. Dose distributions vary greatly depending on pathway, geographic location, season, dairy cow feeding practices, age, and lifestyle. The milk pathway is important because iodine-131 concentrates in milk produced by cows that graze on contaminated pasture.

For people who drank milk, one of the most important determinants of dose was where the milk was produced. Downwind areas had the highest concentrations of iodine-131 on vegetation during a typical summer month. These are also the areas where milk concentrations would have been highest in milk produced by cows on fresh pasture. Some downwind residents, such as those in Richland, drank milk produced in upwind areas and therefore would have lower doses than their neighbors who drank milk produced locally.

Seasons were the next most important factor that influenced doses to milk drinkers. Dairy cows that were grazed on fresh pasture produced milk with the highest concentrations of iodine-131; consequently, highest doses would be expected during the grazing season. Cows that ate alfalfa, hay, green chop, or other feed that was not fresh would have been exposed to much lower levels of iodine-131 because of the relatively rapid decay of iodine-131 during storage. For example, neighbors who had family cows and who drank the same amount of milk and were the same age could nevertheless have had considerably different radiation exposures because of differences in what the cows ate.

Finally, age was a major influence on doses. If an adult and an infant drank equal amounts of milk containing the same amount of iodine-131, the infant's dose to the thyroid would be about 10 times as high as the adult's. Differences in the size of infant and adult thyroid glands is the principal reason for this difference.

Radiation Dose

When radiation enters a person's body, that person receives a radiation dose. Several different terms have been developed to describe these radiation doses. The *rad* expresses the amount of energy deposited by radiation in the body. The rad is the most basic unit of radiation dose, but its use is limited because different types of radiation have different effects on the cells in the body. The *rem* is a unit of radiation dose that takes these differences into account. It puts different types of radiation on an equivalent basis in terms of their potential impact on human cells. A third measure of dose, the *effective dose equivalent (rem) [EDE (rem)]* is used to account for the fact that a rem of radiation dose to one part of the body does not have the same potential health impact as a rem of dose to another part. The EDE (rem) puts different types of radiation doses on an equivalent basis in terms of the potential health risk.

Preliminary Dose Estimates From the Air Exposure Pathway

Dose distributions were combined from hundreds of individual categories representing people who had certain factors or characteristics in common. To give people an overview of the results in this summary, these separate distributions have been combined into categories that are distinguished by the following factors:

- drank/did not drink milk
- lived downwind/upwind (Figure 4.13)
- obtained milk from downwind/upwind
- obtained milk from commercial source/family cow
- obtained milk produced by cows on pasture/feed
- was infant/adult during 1944-1947.

The complete results of Phase I calculations are provided in the draft technical report on the air pathway. Individuals who lived in the Phase I area during 1944-1947 can get an estimate of the range of dose estimates (from the milk pathway) that the preliminary Phase I results indicate might apply to them and how likely these doses were by "walking" through Figure 4.14 and then moving to Figure 4.15. For example, if a person lived in the Phase I area in 1945-1947, drank milk, obtained milk/lived upwind, obtained the milk from a commercial source, and was an adult at the time, then his or her estimated dose is likely to be in the range identified by number 2 in Figure 4.14. Figure 4.15 shows that Category 2 ranges from a dose of about 0.0003 to about 8 rad to the thyroid, that the median (middle) value is at 1 rad, and that about 40% of the Phase I population were likely to have received doses from the milk exposure pathway in that range.

Category 13 in Figure 4.15 shows that infants who drank milk from a family cow that was on pasture downwind had the highest doses. In contrast, Category 4 shows that an adult who drank milk from a family cow upwind and not on pasture had the lowest doses. The ranges account for 90% of the people in each category. Upper and lower values are not included because they are too uncertain. Details concerning the upper and lower values of each of the categories calculated for Phase I are included in the Draft Air Pathway Report. The entire range of dose estimates for the milk pathway is shown in Figures 4.15, 4.17, 4.19, and 4.20.

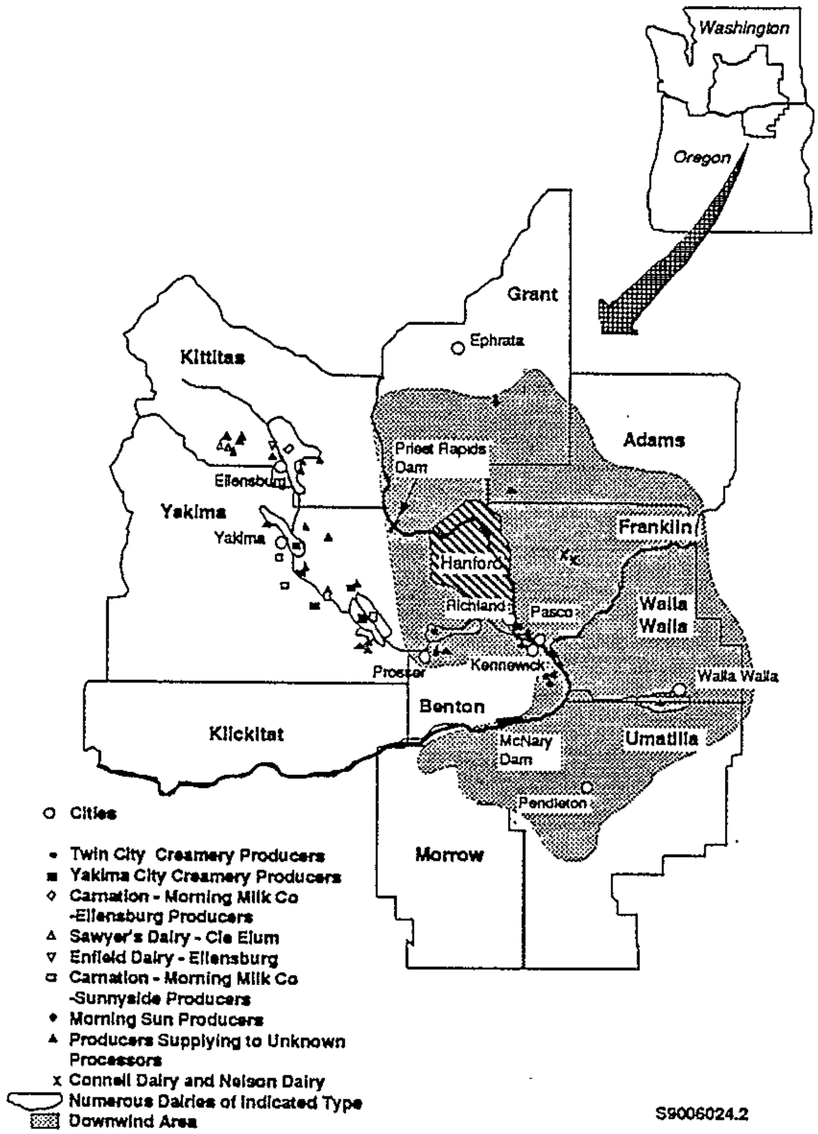


FIGURE 4.13. Milk Producers and Processing Plants Located to Date in the Phase I Study Area, 1944-1950 (shaded = downwind)

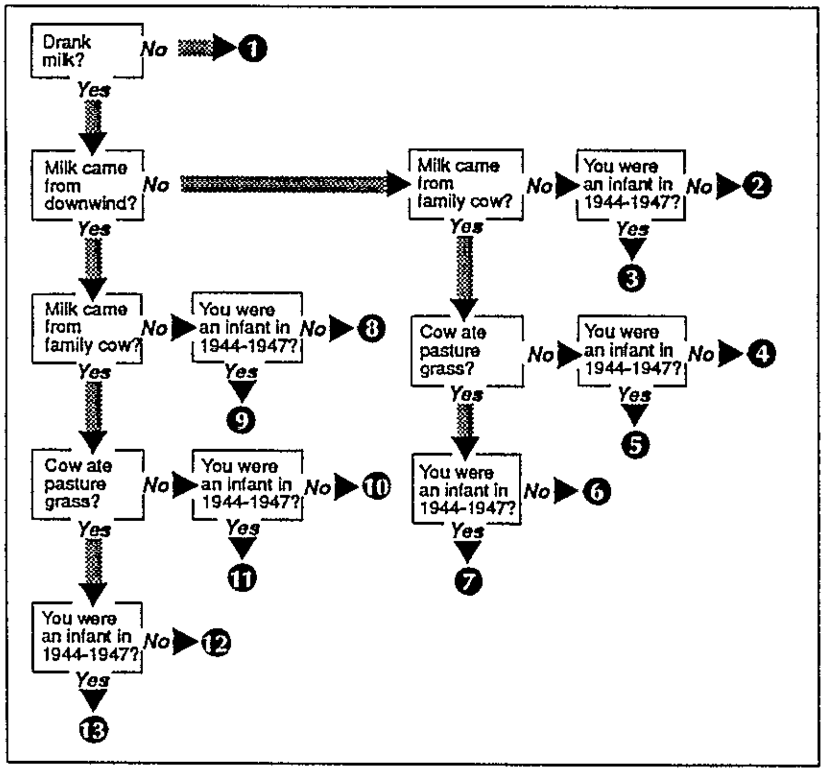


FIGURE 4.14. Guide to Establish Dose Category for People Who Lived in the 10 Counties Closest to Hanford from 1944 to 1947 (see Figure 4.15 for estimated dose ranges)

The distribution of preliminary dose estimates for the milk exposure pathway for the entire Phase I population is shown in Figure 4.16a, b, and c. Figure 4.16a shows the entire range of estimated doses. For example, say a person wants to know what percent of the Phase I study population received an estimated dose greater than 1 rad. He or she would move vertically from 1 rad until intersecting the curving line, then move horizontally to the left until the line intersects the "percent" line (the vertical axis). The point where the intersection occurs is 65, which means 65% of the Phase I study population could have received a dose greater than 1 rad to the thyroid from the milk exposure pathway. Figure 4.16b shows that about 16% of the population could have received a dose of greater than about 10 rad to the thyroid. Figure 4.16c shows that between 1.5 and 2% of the population could have received doses greater than 100 rad to the thyroid. (Doses from drinking goat milk, which could have had higher concentrations of iodine-131 than cow milk, will be estimated during later phases.)

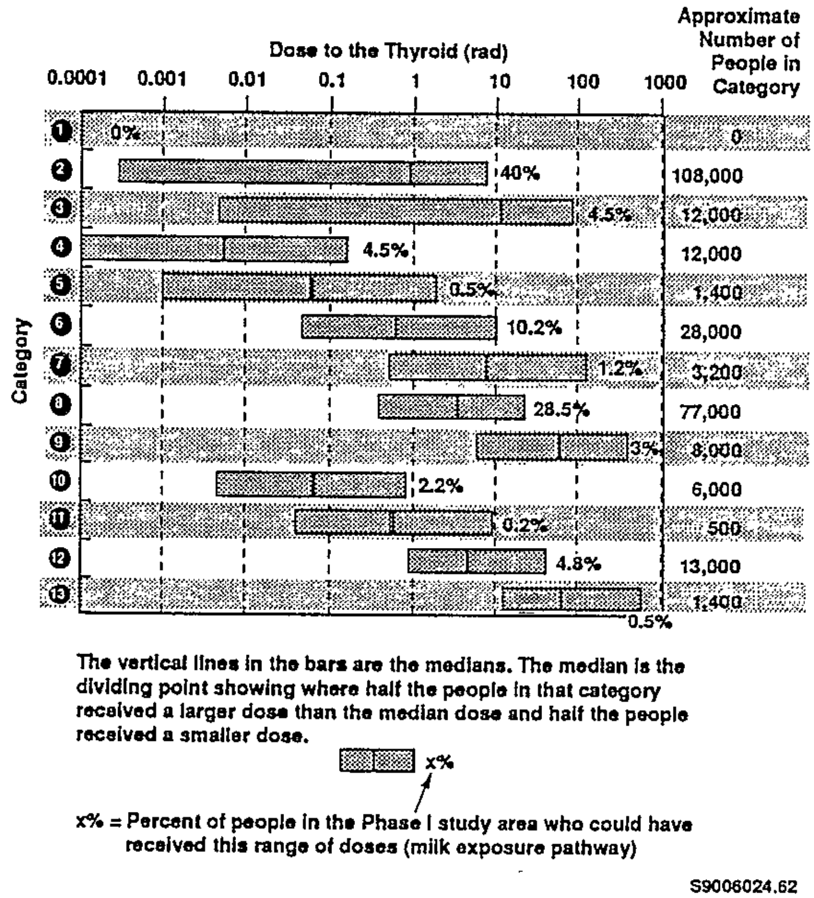


FIGURE 4.15. Ranges of Preliminary Thyroid Dose Estimates, by Category, for 1944-1947 Residents (Ranges cover 90% of the individuals in each category. Upper and lower 5% in each category are shown in the Draft Air Pathway Report.)

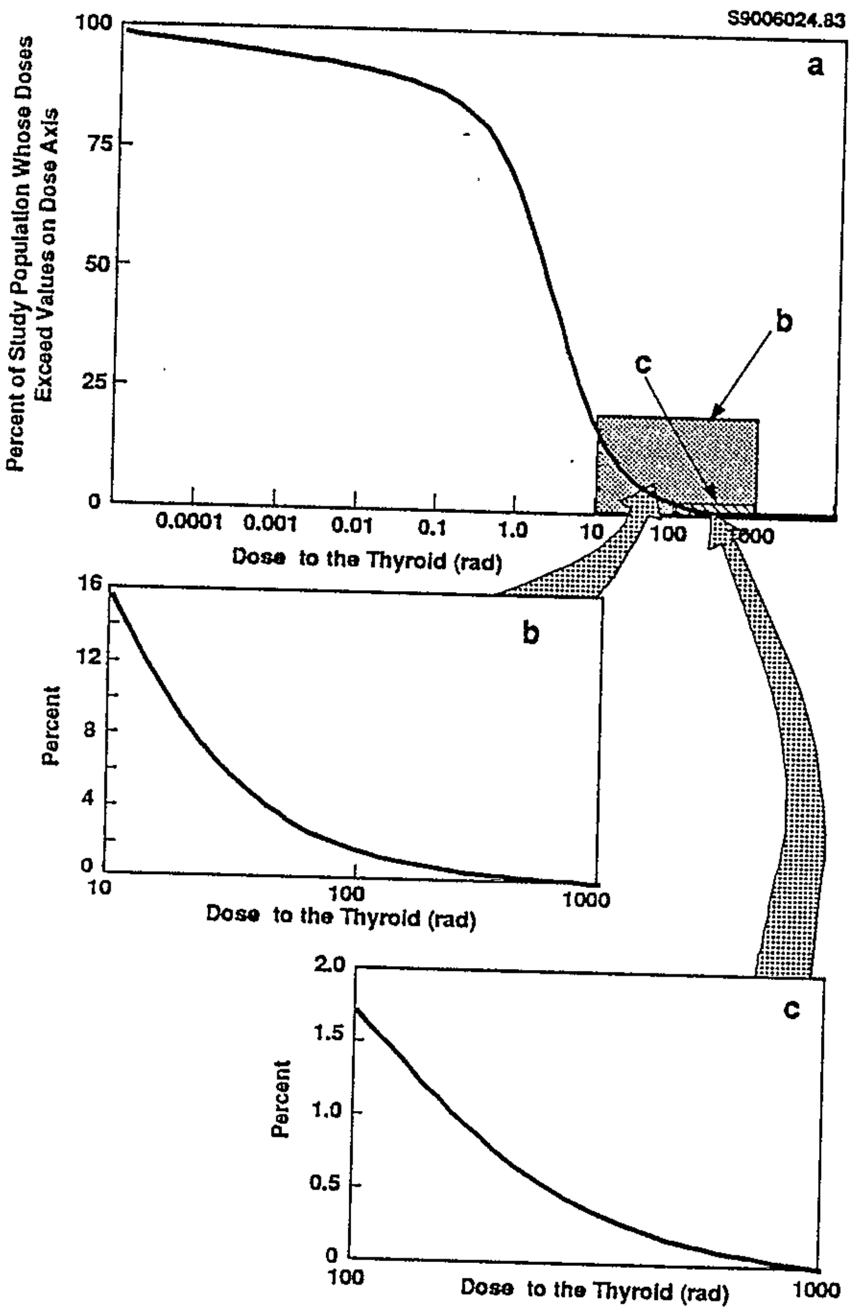


FIGURE 4.16. Preliminary Dose Estimates from the Milk Exposure Pathway, 1945-1947

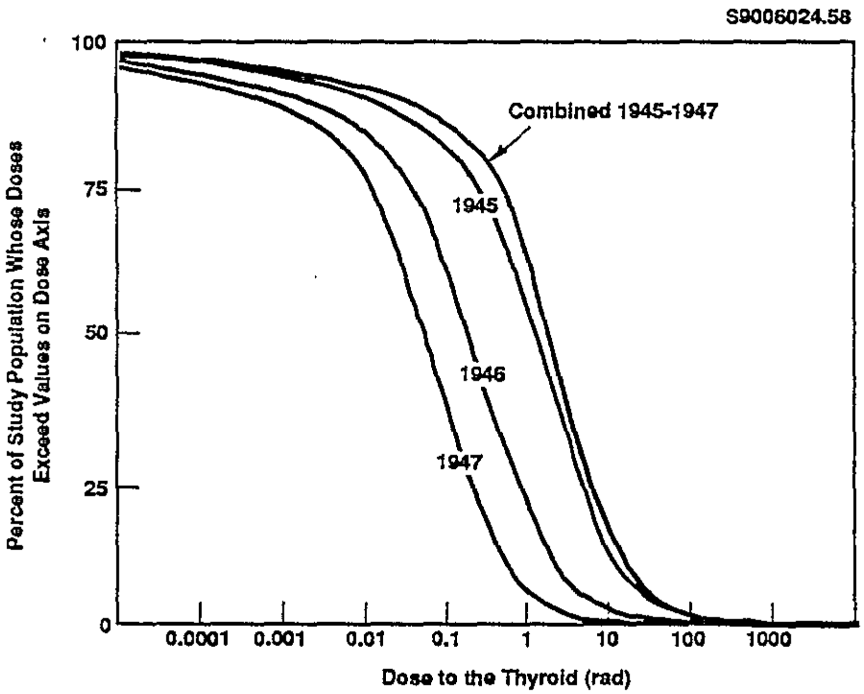
Doses from the milk exposure pathway were highest in 1945 and lower by about seven times in 1946. Doses in 1947 were about 20 times lower than doses in 1945 (Figure 4.17). These decreases directly reflect decreases in estimated amounts of iodine-131 released from Hanford operations during this time period.

In summary, the greatest contributor to the air pathway doses for infants is ingestion of milk; ingestion of locally grown vegetables is second, then inhalation, and finally immersion and external radiation from surfaces contaminated with iodine-131 (Figure 4.18). In the case of adults who ate large quantities of locally grown leafy vegetables and drank locally produced milk, the doses from vegetables could be about the same as doses from consumption of contaminated milk. The milk pathway is more important for infants than adults because infants typically consume less vegetables than adults do.

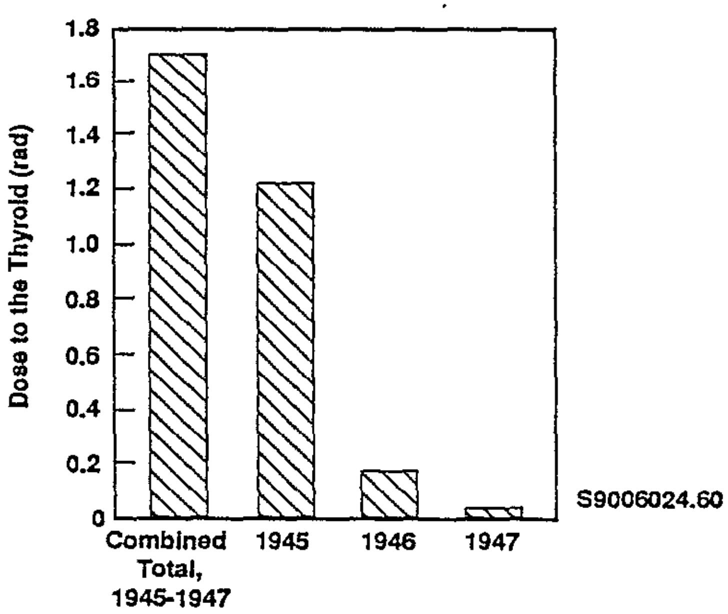
It is important to recognize that radiation doses from the separate exposure pathways shown here cannot be added together to equal the total amount of radiation received by the entire Phase I population. This is because information about where people got their vegetables, fruits, and grain was not available for Phase I. When developing the model input information on potentially contaminated foods, scientists specified that the foods were locally grown. This assumption makes some of the dose estimates from eating these foods come out artificially high.

Scientists know that many people probably did not eat locally grown foods, especially in downwind areas that lacked irrigation. Many foods were grown in areas where wind did not deposit as much radioactive material, then shipped to other areas. In later phases of the project, information about where foods were grown will be reconstructed. Many of the final dose estimates from exposure to contaminated food could be lower than the estimates shown here.

Again, it is critical to recall that Phase I dose estimates are preliminary and are likely to change. Average values might decrease or increase, and the variation, or uncertainty, in the estimates will likely decrease during later phases. Nevertheless, the preliminary distributions provide information about the relative importance of factors such as milk consumption, age, and location that result in higher or lower doses.



(a) Estimated Dose Distributions, 1945-1947



(b) Median Dose Estimates, 1945-1947

FIGURE 4.17. Preliminary Dose Estimates from the Milk Exposure Pathway, 1945-1947

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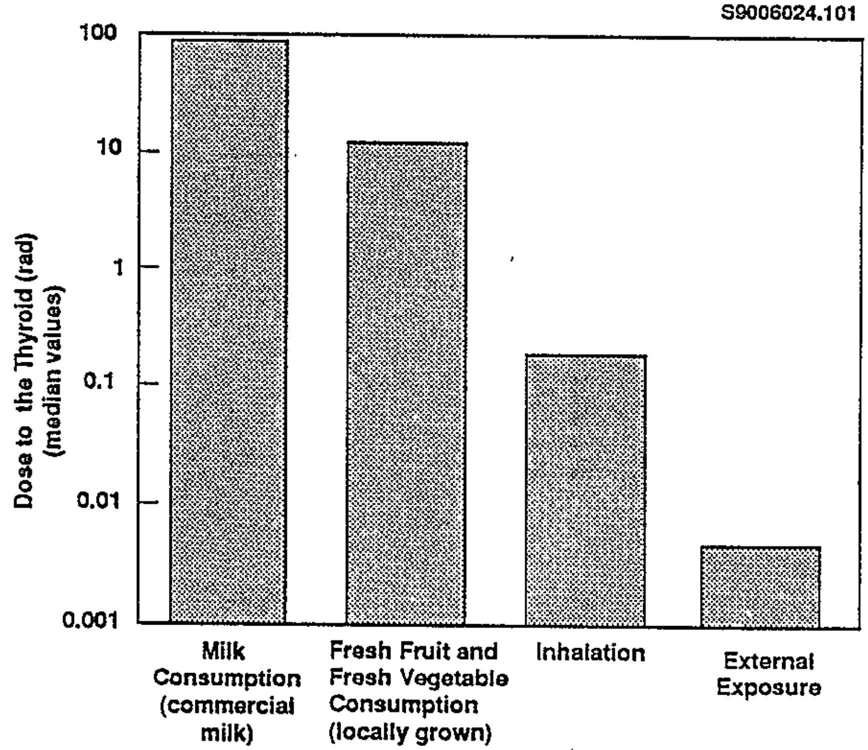

FIGURE 4.18. Comparison of Dose Estimates for Different Pathways of Exposure (city of Walla Walla, infant drinking commercial milk and eating local fruits and vegetables)

4.5 Comparison of Dose Estimates With Background Radiation

One way of helping answer the question, "What do these dose estimates mean to me?" is to compare them with amounts of radiation to which we are typically exposed, called background radiation. Background radiation includes natural radiation, such as the sun, and manmade sources, such as from medical exposure and consumer products.

Background Radiation

Radiation is a natural part of our environment. Radioactive materials from the earth's crust are present in the air, the soil, and the water. They move through the food chain and are present in small amounts in the human body. Radiation from outer space bombards the earth continuously. These two sources make up what is called natural radiation. Everyone is exposed to natural radiation. The amount people are exposed to depends on where they live. People living at higher elevations receive more radiation from outer space because less of the radiation is absorbed by the atmosphere at higher altitudes. One of the most significant sources of natural radiation is radon, which is a gas emitted from uranium in the soil. Soil in some parts of the country has as much as a hundred times more radon than soil in other areas.

Background radiation also includes manmade radiation, such as that used in medical diagnosis and treatment. Dental X-rays are one common form of manmade radiation.

According to a publication of the National Council on Radiation Protection and Measurements (NCRP 1987), the average person in the United States is exposed to about 0.36 EDE (rem) a year, most of which is due to naturally occurring radioactivity, or to about 25 EDE (rem) during an average lifetime.

Dose Rate

Dose rate expresses how a radiation dose is accumulated over time. The effect of radiation on the body is very dependent on the rate at which a dose is received. If the body receives a large dose of radiation over a small period of time such as minutes or hours, radiation sickness could result. However, the same dose received over a long period of time, such as 10 or 20 years, might result in no health effects, or at most, a small increase in the chance the exposed individual might contract cancer.

These amounts of non-Hanford radiation sources are compared with amounts of radiation people could have received from the milk exposure pathway from Hanford from 1944-1947 are shown in Figure 4.19. The risk from radiation at any particular time in a person's life depends on the amount of radiation received up to that point. For example, if a person received an average background dose of 0.36 rem a year from birth, then at age 10, the total (or cumulative) dose would be 3.6 rem. This is the amount that would be used to estimate risk. About 5% of the doses are estimated to be higher than the annual, national, average background amounts added over 3 years. (This is similar to adding together the dose from the Phase I time period of 3 years, 1944-1947.) If a person only lived in the Phase I study area from 1945-1947, the dose from Hanford today would still be the amount received from 1945-1947. However, that person would have received about 42 years of background radiation, which, for the average value, would have added to about 15 rem. About 1% of the doses might have been greater than an average, national, lifetime dose from background radiation.

4.6 Checking the Dose Estimation Model

One way of testing the computer model that makes dose estimates is to compare its results with separate, independent information. If the computer model was designed accurately, its results should be in the same range as other, similar information not calculated by the computer. The independent information used for the comparison included other estimates and actual measurements of radionuclides in the environment and in people. For the air pathway, this independent information included

- measurements of radiation in vegetation

- preliminary, limited dose estimates issued in 1986 by the Washington State Department of Social and Health Services
- measurements of certain radionuclides in the thyroid glands of Hanford workers.

Preliminary results of the HEDR Project were consistent with the numbers contained in the independent information. The result of this comparison indicated that the computer model was working as intended.

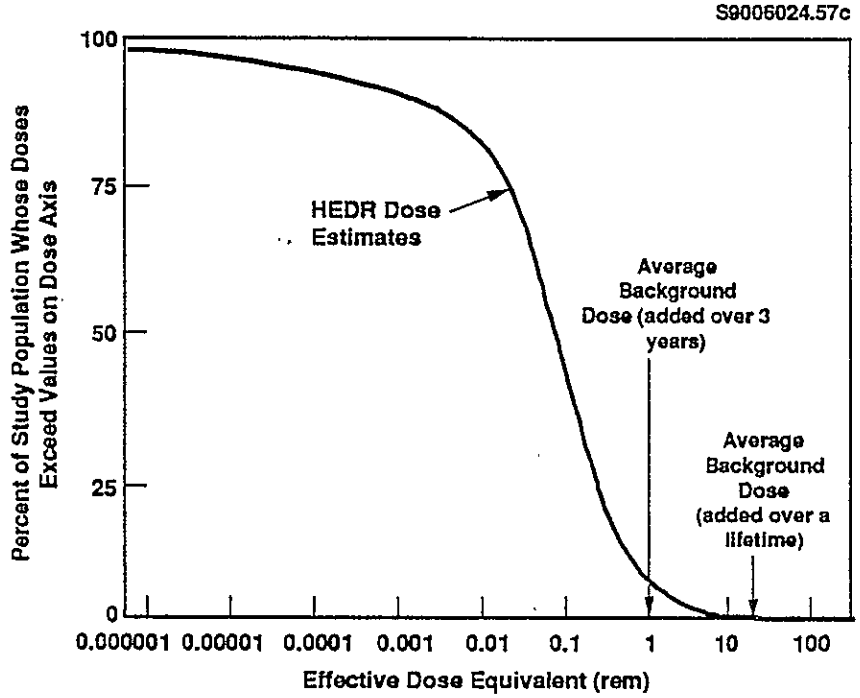

FIGURE 4.19. HEDR Dose Estimates (milk exposure pathway) Compared with Background Radiation

Independent Preliminary Dose Estimates

In 1986, the Washington State Department of Social and Health Services issued a preliminary dose estimate to the public from Hanford radiation (Washington State Office of Radiation Protection 1986). This preliminary estimate was based on historical measurements of iodine-131 on sagebrush and used a modified model for a maximally exposed individual (U.S. Nuclear Regulatory Commission 1977). The Washington State and HEDR Project dose estimates are compared in Figure 4.20. About 0.004% of the population in the Phase I study area might have received doses to the thyroid greater than a previously published dose estimate by the Washington State Department of Social and Health Services (DSHS). The DSHS estimate was a thyroid dose of 2,530 rem to a maximally exposed infant in Pasco, 1945-1947.

Rem, as used by the DSHS for its thyroid dose estimate, is about equivalent to rad as used in this report. This use of rem should not be confused with EDE (rem) used elsewhere in this report.

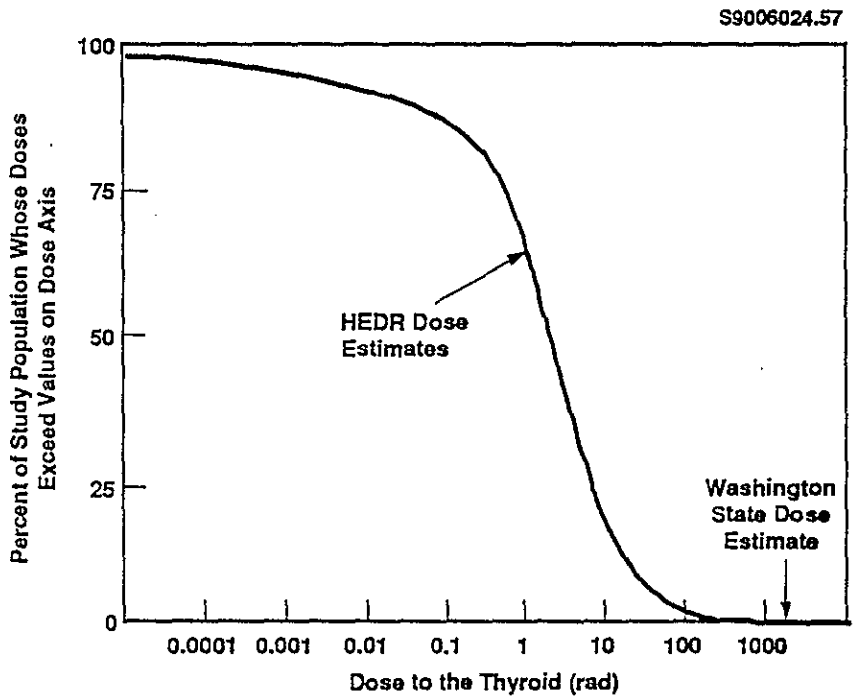

FIGURE 4.20. HEDR Dose Estimates Compared with Washington State Dose Estimate (Pasco infant, 1945-1947)

Thyroid Counts

From the time Hanford operations began, workers in areas likely to experience relatively higher air concentrations of iodine-131 had their thyroids checked with a portable radiation detector. The thyroid checks were used as a way to detect potentially high doses, not to obtain highly accurate measurements. The intent was to detect levels above some arbitrary threshold, which was about 10% of the adopted guidelines.

Records of more than 7,900 measurements of thyroids taken from 1944 to 1946 were examined (Ikenberry 1990). More than one-third of the measurements did not register above background radiation levels because of a combination of relatively high background levels, relatively insensitive instrumentation, and low amounts of iodine-131 in the thyroid glands of the workers monitored.

The distribution of dose estimates based on the thyroid counts are compared with estimates of inhalation doses calculated by the HEDR Project for adults living in Richland from November 1945 through February 1946. As is evident in Figure 4.21, doses based on the thyroid checks are similar to the median (middle) values calculated by the HEDR Project for December 1945, but somewhat higher earlier and later. The higher worker thyroid counts probably reflect exposure to higher concentrations of radionuclides while at work and to pathways other than just inhalation.

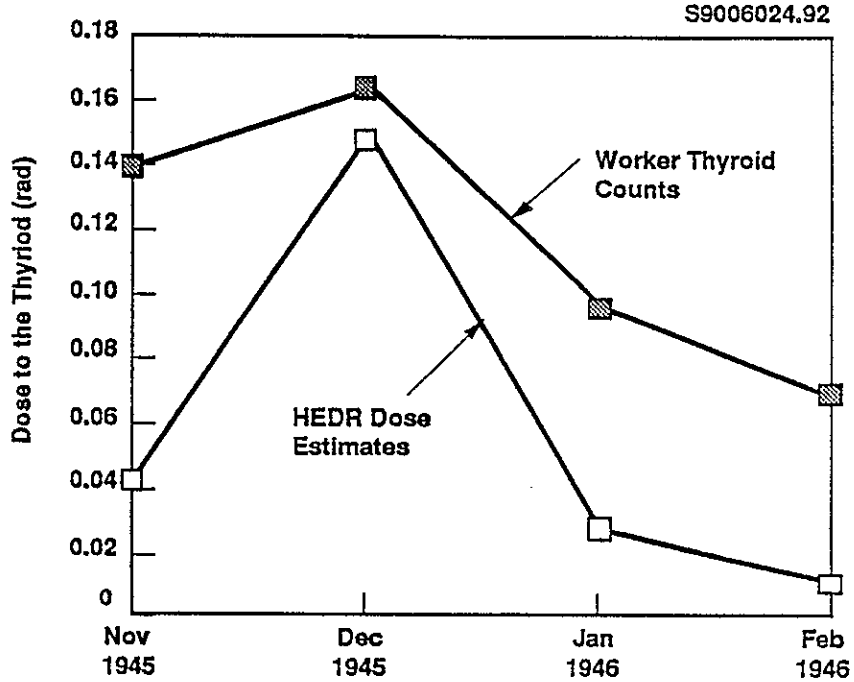

FIGURE 4.21. HEDR Dose Estimates (Richland adults, inhalation exposure pathway, median values) Compared with Measurements of Radiation in Thyroid Glands of Hanford Workers (median values)

Measuring Radioactivity in the Thyroid Gland

Iodine-131 concentrates in the thyroid gland, a small organ in the neck below the Adam's apple. The thyroid gland regulates metabolism. In the late 1940s, the thyroid glands of Hanford workers were checked to determine whether they had been exposed to iodine-131 on the job. A portable Geiger counter was used to measure gamma radiation emitted from any radioactive iodine present in the thyroid gland. The detector was placed lightly against a worker's neck near the thyroid. Because the thyroid is two-lobed, like a butterfly shape, one check was done on the right side and one on the left. Radiation measurements from both sides were recorded.

Today, medical personnel examine the thyroid gland for disease by feeling the thyroid to check its size and shape, by doing blood or other laboratory tests, or by taking scans to see the actual gland.

Guidelines, Regulatory Standards, and Operating Limits

Nuclear facilities in the United States are regulated to control releases of radionuclides to the environment. The regulations often specify the amounts of radiation allowed to be released to the environment. The regulations are implemented by limiting operations in such a way that releases are maintained within the regulatory standards.

When Hanford operations began in 1944, there were no national regulatory standards and no nuclear plant experience to use in setting standards. Instead, guidelines were established on the basis of recommendations from the medical community. These guidelines were based on standards that had been established to limit exposure of medical workers to radiation. Early Hanford guidelines allowed worker exposures at most to be one-half of the levels recommended by the medical community. As experience in monitoring releases, in monitoring the environment, and in monitoring personnel was gained and as monitoring technology improved, allowable exposures were lowered for more protection of people. In the 1950s, national regulatory standards were implemented.

4.7 Historical Regulatory Standards

Some readers may be interested in what guidelines were used to control radiation exposures in 1944-1947. Hanford Site officials adopted guidelines recommended by the medical profession for exposure of medical employees and reduced the allowable exposures for Hanford employees to half of those guidelines (Wilson 1987).

Exposures to iodine-131 were based on amounts that could be inhaled during a 24-hour period. The guideline translates roughly to about 1 rad to the thyroid per day. (There was also a guideline for vegetation in efforts to protect sheep and cattle that might graze on contaminated forage.) The guideline was not based on doses that might result to offsite populations from drinking contaminated milk because that pathway was not recognized as being the critical pathway until the mid-1950s (Comar et al. 1957; Parker 1956).

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5.0 Columbia River Exposure Pathway

Phase I consists of two parts: 1) reconstructing potential radiation doses from the release of radioactive materials into the atmosphere, and 2) reconstructing potential doses from the release of radioactive materials to the Columbia River and to soils on the Hanford Site. This chapter covers the exposure pathway of the Columbia River, which includes the pathways of radionuclides in soil and ground water.

5.1 Approach

Radiation dose estimates that the public may have received from Hanford radiation have been made and published in annual reports since 1957. Therefore, the reader may wonder why doses were re-estimated for the 1964-1966 time period, rather than just using the published ones. New estimates were made because the published estimates give only one possible amount of radiation received for an "average" individual and one value for a "hypothetical" person exposed to the maximum possible radiation by that person's lifestyle (for example, the person ate the largest possible amount of fish from the river, drank the largest possible amount of water from the river, and so on.) In contrast, the HEDR dose estimates provide a range of possible doses depending on the way people could have been exposed.

The existing published estimates were compared with the HEDR Project estimates to check the validity of the part of the computer model that estimates radiation doses from exposure to the river pathway.

Area

The Phase I study area for the river pathway was selected to include the communities immediately downstream of the Hanford Site and therefore most likely to have received the highest doses from drinking treated Columbia River water or from eating fish caught in this area (Figure 5.1). Areas open to fishing and recreation, municipal withdrawals of river water, and monitoring locations are shown in Figures 5.2 through 5.5.

The area between Priest Rapids Dam and McNary Dam was also selected because up to 80% of the people who drank treated Columbia River water between Hanford and the river mouth lived along this stretch of the river during the Phase I time period of 1964-1966.

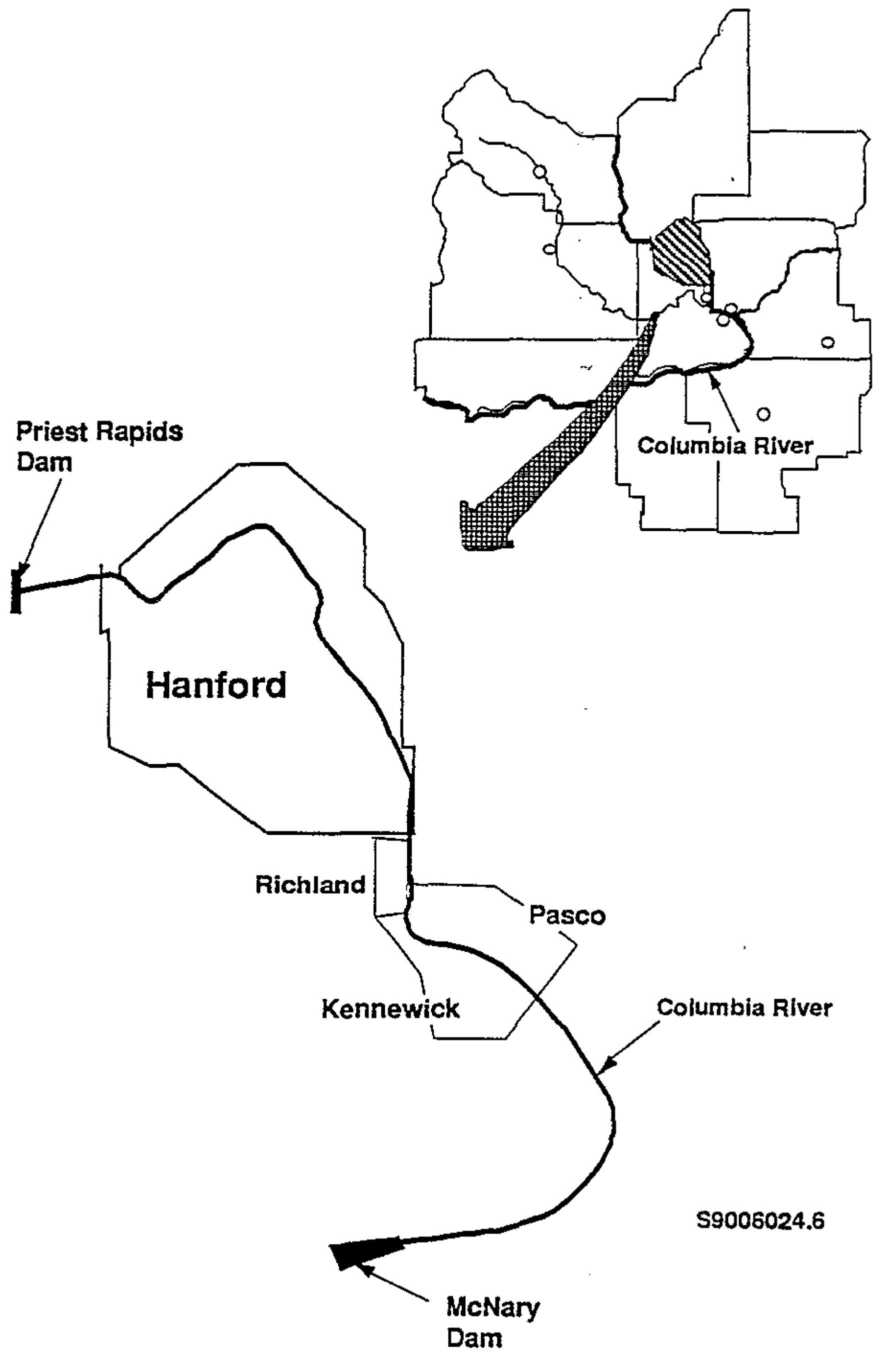

FIGURE 5.1. Phase I Area for Estimation of Doses from Exposure to Columbia River Water or Fish

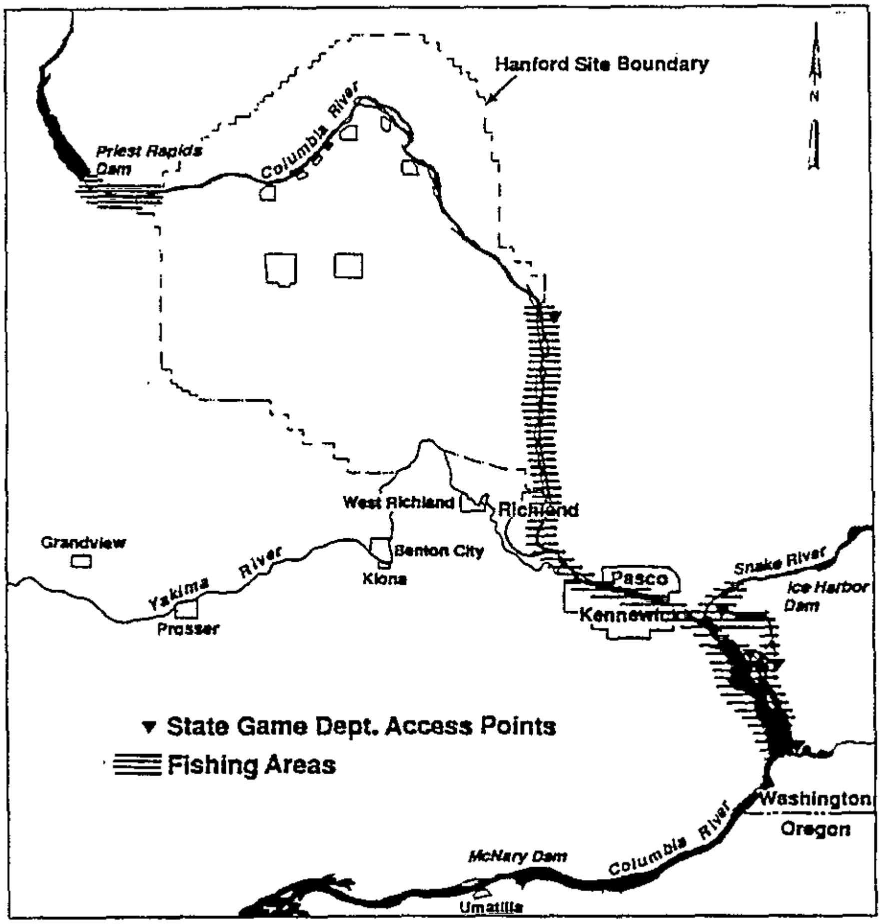

FIGURE 5.2. Fishing, 1964-1966

Time Period

The Phase I time period of 1964-1966 for water exposure was selected for several reasons. Richland is the community closest to Hanford and most likely to have received the highest doses from drinking treated Columbia River water. Richland did not used Columbia River water until 1964. Doses for Pasco and Kennewick residents, who used Columbia River water, were known to be lower because

- Pasco and Kennewick are farther downstream than Richland, giving short-lived radionuclides more time to decay
- Pasco and Kennewick are downstream of the confluence of the Yakima River, resulting in greater dilution of radionuclides
- Kennewick residents obtained water from river shore wells, which helped filter some radioactive materials from the water before it reached the treatment plant.

The Phase I time period was also selected because

- extensive monitoring data were available (Foster and Wilson 1965; Foster, Soldat and Essig 1966; Foster, Moore and Essig 1966; Honstead and Essig 1967; and Honstead, Essig and Soldat 1967)
- continuous sampling (cumulative samplers) began in 1964 and provided better estimates of concentrations of longer-lived radionuclides
- all reactors were still in operation in 1964 and were at the highest historical power levels (Figure 5.6)
- data from independent sources such as the state of Oregon and the U.S. Geological Survey are available (Toombs and Cultor 1968; Nelson et al. 1966).

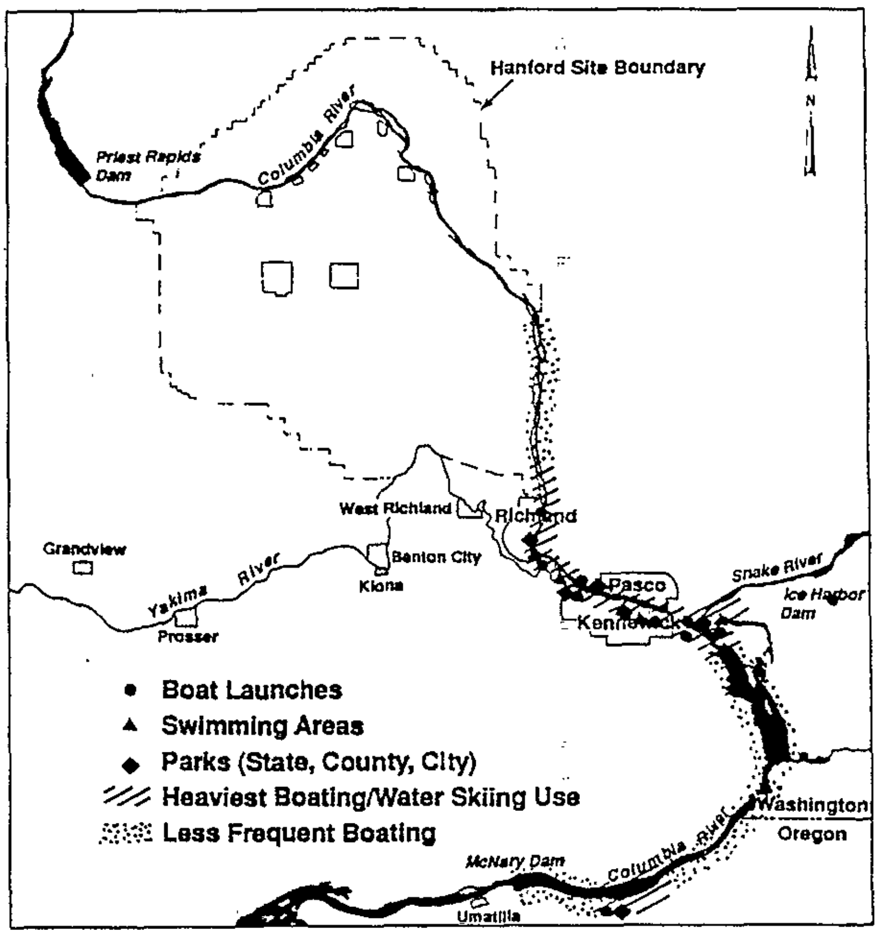

FIGURE 5.3. Recreation, 1964-1966

Reactor Power Levels and Radionuclide Releases to the Columbia River

Most of the radionuclides released to the Columbia River in cooling water discharges from the reactors resulted from the irradiation of impurities in the cooling water and from the irradiation of material on cooling water pipes in the reactors. The amount of radionuclides released to the river depended on the number of reactors operating and their power levels. As the number of reactors and the power levels of the reactors increased, the amount of radionuclides released to the river increased. In the early years of Hanford operations, two or three reactors operated, and power levels were relatively low. As the number of reactors increased from two or three to eight, the power levels also increased. By the early 1960s, the total power level of the reactors was from 10 to 20 times higher than power levels in the late 1940s and early 1950s. Consequently, radionuclide releases to the Columbia River were highest during the late 1950s through the middle 1960s, with the highest level achieved just before the first of the original reactors was shut down in December 1964.

Finally, the early years of operation (1944-1947, the Phase I air pathway period) were not selected for the Phase I demonstration/feasibility study because only two to three reactors were operating then and because the total power of the reactors was less than one-twentieth of the levels in the peak years from 1960 through 1964. Radioactive discharges into the Columbia River were related to these power levels (Honstead, Essig, and Soldat 1967).

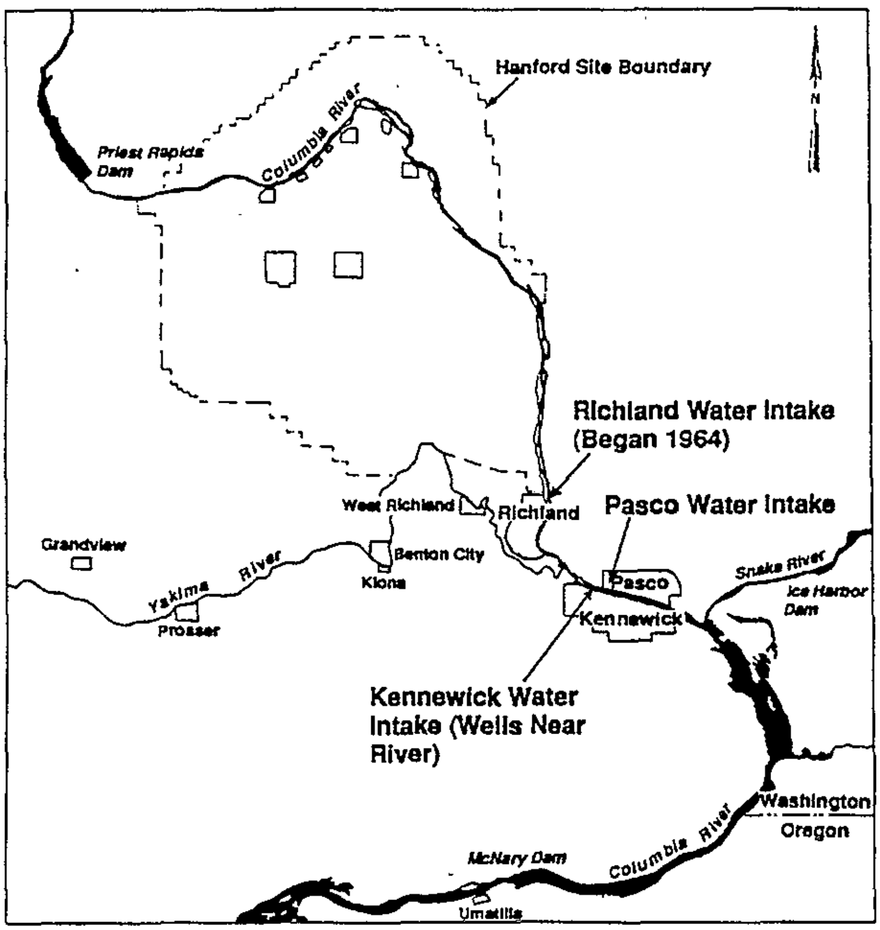

FIGURE 5.4. Municipal Water Supply, 1964-1966

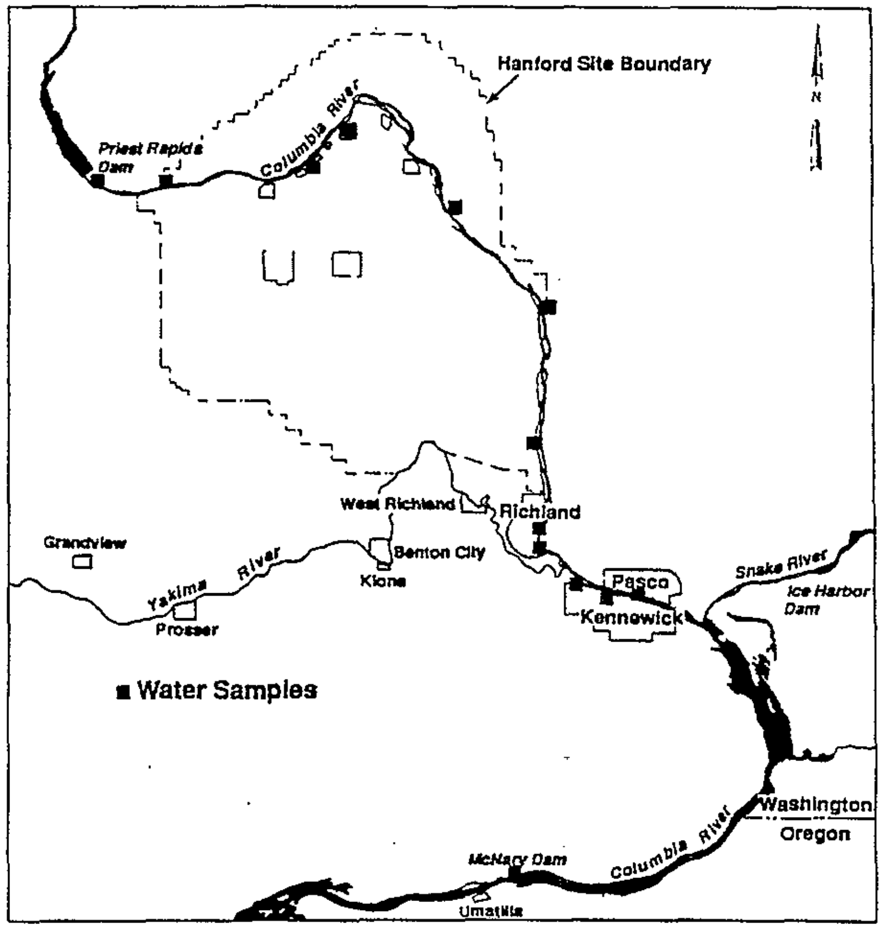

FIGURE 5.5. Monitoring Locations, 1964-1966

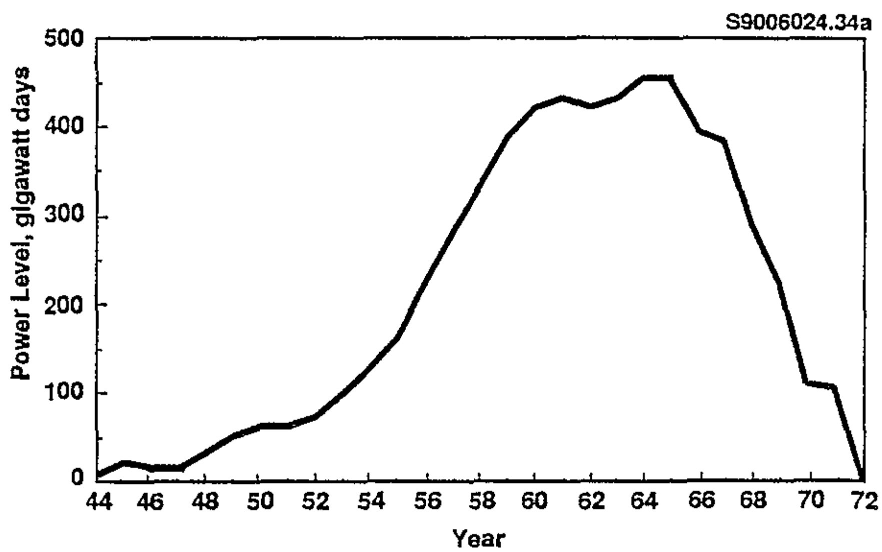

FIGURE 5.6. Approximate Power Levels of Hanford Reactors Over Time (Harty et al. 1978)

Key Radionuclides of the River Exposure Pathway

Of the many radionuclides released to the Columbia River with cooling water from the reactors, eight of these accounted for most of the radiation dose to downstream residents. Phosphorus-32 was the most important of these eight radionuclides. Phosphorus-32 resulted from the irradiation of the element phosphorus in the cooling water as it passed through the reactors. This radionuclide is absorbed by aquatic organisms and moves through the food chain to fish. As a result, fish that eat aquatic organisms contaminated with phosphorus-32 may accumulate amounts of this radionuclide that are hundreds to thousands of times as high as the amounts in the river.

Some fish containing phosphorus-32 were eaten by people, which exposed them to radiation given off by the phosphorus-32. The radiation dose received by people who ate fish depended on the amount of fish eaten, the amount of phosphorus-32 in the fish, and whether the fish were eaten fresh or not. Phosphorus-32 has a half-life of 14 days, meaning half the radiation disappears every 14 days. If fish containing phosphorus-32 was stored for 2 weeks before it was eaten, it would have contained half as much phosphorus-32 as when it was fresh. If the fish was stored for 6 weeks before being eaten, it would have contained one eighth as much, and so on.

Radionuclides

The original eight reactors were cooled with treated river water that passed through the reactors and was discharged into the river. Some of the naturally present chemical elements in the cooling water, as well as chemicals added in the treatment process, became radioactive and were discharged. Scale and other materials also built up in the cooling system, became radioactive, and were sloughed off and discharged into holding basins and then into the river. This built-up material also affected the flow of water through the reactors and was therefore periodically removed with a scouring material. These "purges" resulted in increases in radioactive releases during the scouring and then decreases until material built back up in the cooling system. Radionuclides were also released to the river when fuel elements accidentally ruptured. The downstream monitoring systems accounted for all three sources of radionuclides: 1) routine releases from the cooling system, 2) periodic releases from purging, and 3) accidental releases from fuel failures.

The N Reactor was designed with a secondary cooling system so that the river water would not pass through a radiation field; consequently, naturally present chemical elements in the cooling water would not become radioactive.

As in the case of the air pathway, not all radionuclides discharged from the reactors in cooling water contributed significantly to dose. The dose received from the radionuclides depends on many factors, including whether they were consumed via drinking water or fish, or whether they contributed to exposures while people were swimming, boating, or engaging in other recreational activities along the river bank (Napier 1990). The dominant radionuclides considered for the river pathway are

- arsenic-76
- chromium-51
- copper-64
- manganese-56
- neptunium-239
- phosphorus-32
- sodium-24
- zinc-65.

Exposure Pathways

Figure 5.7 shows ways people could have been exposed to radionuclides released into soil or the Columbia River. Soil, ground water, and Columbia River water are discussed in this section.

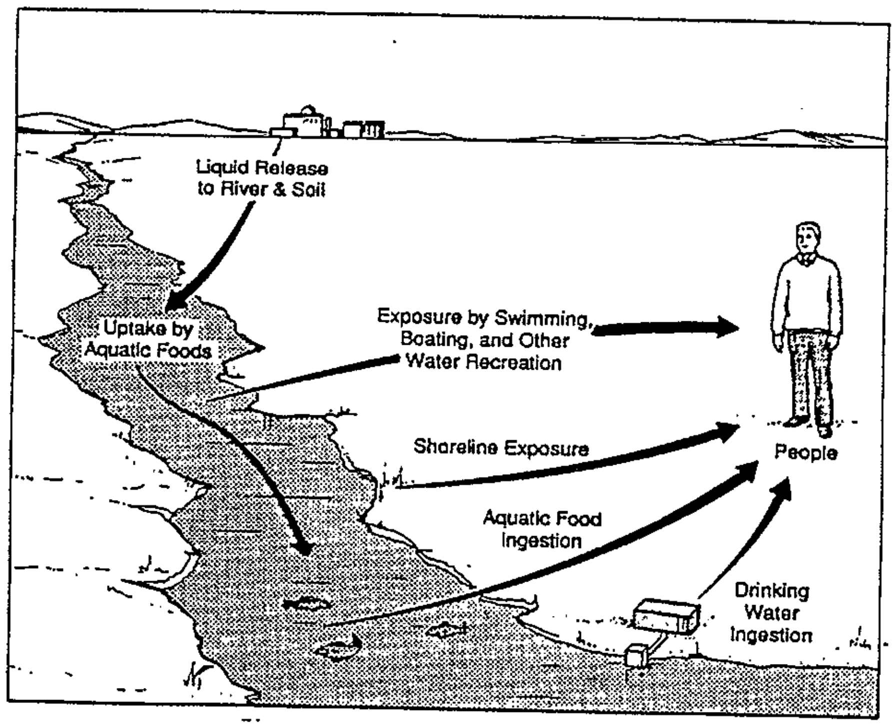

FIGURE 5.7. Potential Radiation Exposure Pathways from Radionuclides in the Columbia River

Soil and Ground Water - From the time Hanford facilities first began operating, highly radioactive liquids were routed to underground storage tanks, and less radioactive liquids were discharged directly to ponds, ditches, and engineered structures called cribs. Some of the radioactive liquids moved through the soils into ground water. Some, such as tritium, traveled in the ground water to be discharged into the Columbia River. These radioactive liquids contributed very little to the much larger amounts of radioactive liquids that were routinely discharged into the Columbia River as part of the cooling water from the original reactors. In any case, because Phase I dose calculations for the Columbia River pathway are based on environmental monitoring data, radionuclides that might have entered the Columbia River from ground water in detectable amounts are included in the Phase I dose calculations.

Ground Water

There are underground reservoirs of water all over the earth. This underground water is called ground water. Wells tap into these underground reservoirs to withdraw water for humans. Ground water reservoirs are connected to rivers and lakes. Water above ground can also reach ground water by slowly seeping through soil, which could carry contamination from the surface to the ground water.

Columbia River Water - Drinking water exposed more people in the Phase I study area to radiation than did eating fish, but people who ate large quantities of certain kinds of fish from the Columbia River would have had higher doses. Some species, such as salmon and steelhead trout that are caught as they migrate upstream from the ocean to spawn, typically contained lower concentrations of radionuclides than did non-migratory fish. Other activities, such as swimming, boating, or walking along the river shore, resulted in exposures that were, on the average, considerably lower than exposures from drinking water and eating fish. Small exposures could also result from irrigating crops with water from the Columbia River. This pathway was not included in Phase I work, but will be considered later in the project.

5.2 Input Information

The primary input information for the river pathway dose calculations is monitoring data and information about the locations of populations using treated river water for drinking.

Monitoring data are available from several steps in the path from releases to the Columbia River to concentrations of radionuclides in people (Figure 5.8). Measurements of discharges from each reactor were taken daily in 1964-1966. Weekly measurements (continuous during the week and one-time) were taken of river water at several locations. Drinking water was sampled at

Richland, Pasco, and to a lesser extent, Kennewick. Several kinds of fish were sampled, especially whitefish, which could be caught year round and had among the higher concentrations of important radionuclides, such as phosphorous-32. Measurements were also made of external radiation along the river bank from sediments containing radionuclides.

Where available data were limited in space or in time, measurements of releases from the reactors were used along with information about dilution in the river to calculate river concentrations used as input to the Phase I dose calculations.

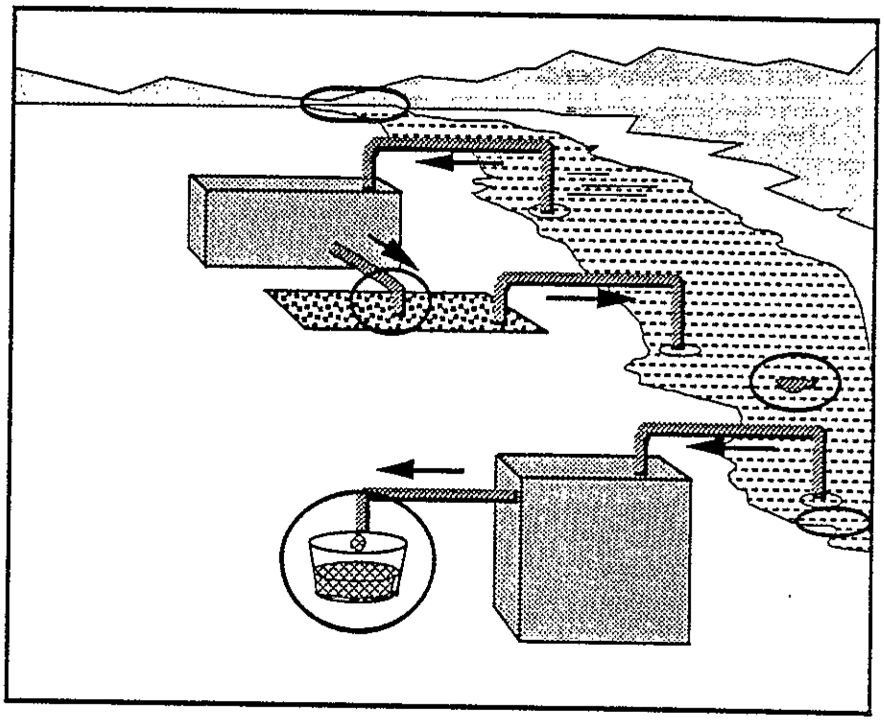

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FIGURE 5.8. Where Waterborne Radionuclides Are Monitored

5.3 Output Information

Recall that output information for the air exposure pathway consisted of iodine-131 concentrations in the environment and dose estimates. In contrast, the river pathway calculations used measured concentrations of several different radionuclides as input information and produced only dose estimates as output. A second difference between the air and river pathway calculations is the parts of the body irradiated by the radionuclides that were inhaled or ingested. Several radionuclides were studied for the river exposure pathway, and each has one or more areas of accumulation in the body.

A difficulty arises if we want to compare doses from the various river exposure pathways. The same doses to different organs can result in different risks of health effects. The concept of measuring radiation in Effective Dose Equivalent (EDE) (rem) is used to overcome this difficulty. The EDE puts different types of radiation doses on an equivalent basis in terms of potential health risk. Organ doses are given different degrees of importance depending on their relative risks. In this way, pathways can be compared in terms of their relative importance. For example, doses from eating fish can be higher than those from drinking water for individuals who ate large quantities of contaminated fish.

5.4 Preliminary Dose Estimates from the Columbia River Exposure Pathway

Doses were estimated for individuals who represented people with certain shared characteristics. These distributions were then combined into the following categories:

- ate/did not eat Columbia River fish
- ate/did not eat more than 20 fish meals per year
- fished upstream of Richland and downstream of the reactors/downstream of Richland
- lived/did not live in the Tri-Cities (drank untreated river water)
- lived in Richland, Pasco, or Kennewick.

Individuals who lived along the Columbia River and/or fished in the river in the Phase I area (that was previously shown in Figure 5.1) during 1964-1966 can estimate the range of dose values that might apply to people most like them, and how likely these doses were. This is done by first "walking" through Figure 5.9 and then moving to Figure 5.10. For example, if a person ate less than 20 meals of Columbia River fish per year, fished upstream of Richland and downstream of the reactors, and lived in Richland during 1964-1966, his or her estimated dose is likely to be in the range identified by number 12 in Figure 5.10. Category 12 ranges from about 0.04 to about 0.07 EDE (rem).

Preliminary estimates of doses for Richland, Kennewick, and Pasco residents from drinking water are depicted in Figure 5.11. Doses from drinking water are lower at Pasco than Richland, and lower in Kennewick than Pasco.

The most important river pathway was consumption of fish, especially resident fish, in areas above Richland where fish consumed the highest levels of radionuclides. The highest doses would have been to individuals who drank untreated (raw) river water near Richland and ate large amounts of fish caught upstream of Richland (category number 17 in Figure 5.10).

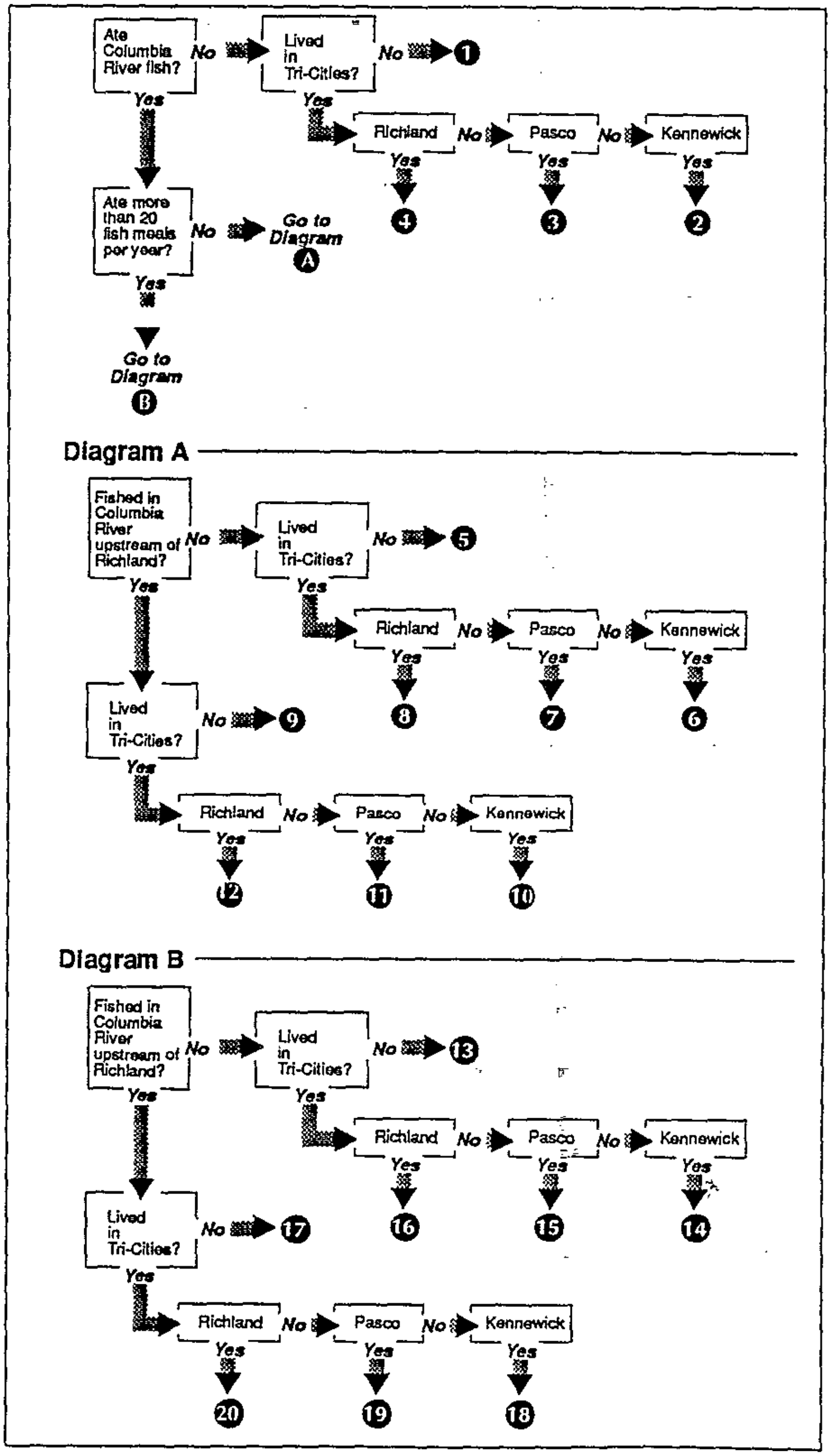
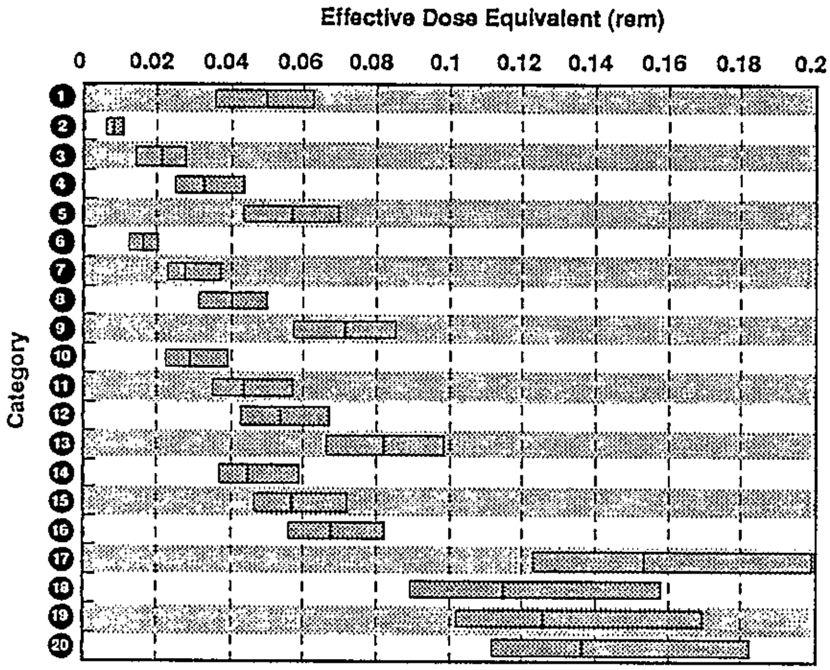


FIGURE 5.9. Guide to Establish Dose Category for People Who Lived Along or Fished in the Columbia River Between Priest Rapids Dam and McNary Dam, 1964-1966 (see Figure 5.10 for estimated dose ranges)



The vertical lines in the bars are the medians. The median is the dividing point showing where half the people in that category received a larger dose than the median dose and half the people received a smaller dose.

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FIGURE 5.10. Ranges of Preliminary Dose Estimates, by Category, for 1964-1966 Residents (Ranges cover 90% of the population in each category. The highest and lowest dose estimates are available in the Draft Columbia River Pathway Report.)

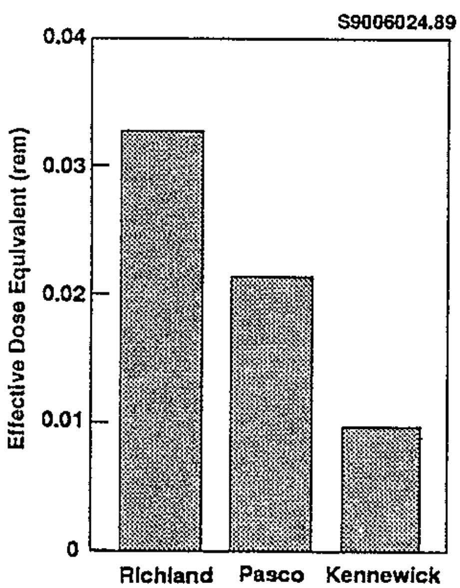

FIGURE 5.11. Estimated Median Doses from the Drinking Water Pathway for Tri-Cities Residents, 1964-1966

5.5 Comparison of Dose Estimates with Background Radiation

To help the reader interpret what the dose estimates mean to them, the estimates can be compared with background radiation from natural and manmade sources. As was explained in Section 4.5, the average person in the United States is exposed to about 0.36 EDE (rem) a year, most of which is from naturally occuring radiation (NCRP 1987).

It is unlikely that any of the population living in the Tri-Cities in 1964-1966 might have received doses added over each of the 3 years from the river pathway that were higher than the amount of annual, average dose from background radiation [0.36 EDE (rem)].

5.6 Checking the Dose Estimation Model

An independent assessment of the degree to which the Phase I river pathway dose estimates reflect actual doses that people might have received was possible by comparing doses calculated by HEDR with previously published dose estimates. Beginning in 1959, an instrument known as a whole-body counter was used to measure the amounts of certain radionuclides in people working on the Hanford Site (Roesch, McCall, and Palmer 1960). Measurements are also available from schoolchildren in the Tri-Cities who were measured during 1965-1968. These measurements can also be used to check HEDR results.

Previously Published Dose Estimates

Dose estimates for offsite populations were first published in annual monitoring reports in 1957 and have continued to be published annually. In these reports, dose estimates were calculated for "average" or "typical" individuals and for "hypothetical maximum" individuals and included contributions from all exposure pathways. (Average, typical, and hypothetical maximum individuals are defined in the published reports.) The previously published estimates for 1964-1966 are compared with HEDR Phase I preliminary dose estimates in Figure 5.12. The previously published "average" or "typical" dose of a Richland resident was within 20% of HEDR Project estimates. About 50% of the Richland population was likely to have received river pathway doses greater than an EDE of 0.035 rem.

Whole-Body Counts of Hanford Workers and of Schoolchildren

About 4,700 records of whole-body counts of Hanford workers are available for the period 1964 through 1966. About 5,000 records are available for schoolchildren for the period 1965 through 1968 (Endres et al. 1972). These records contain data on several radionuclides that could be readily detected with the whole-body counter. Of particular interest to the HEDR Project was zinc-65 that had been absorbed by the body from drinking treated Columbia River water, eating Columbia River fish, or eating produce that had been irrigated with Columbia River water downstream of the reactors.

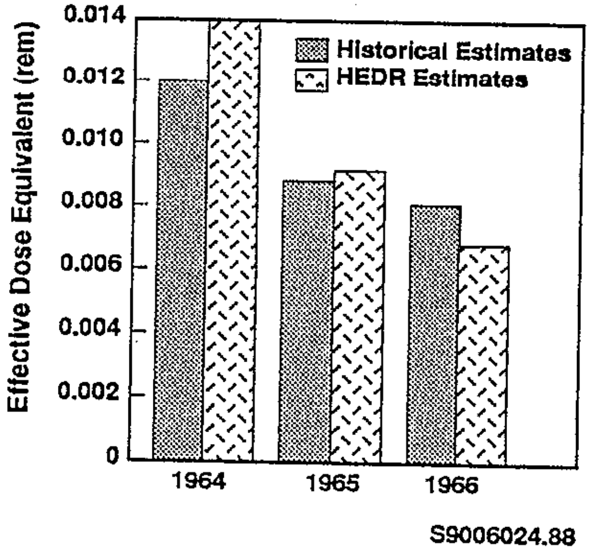

FIGURE 5.12. Previous Dose Estimates for 1964-1966 (average values) Compared with HEDR Dose Estimates (median values) (Richland adults, drinking water pathway)

Dose estimates based on previously published, whole-body measurements of zinc-65 in Hanford workers are slightly lower than the fraction of HEDR calculated doses attributable to zinc-65 (Figure 5.13). Previous whole-body measurements of school-children are also slightly lower than HEDR-calculated body burdens of zinc-65. These comparisons indicate that the HEDR model appears to produce good representations of actual measurements from the 1960s.

5.7 Historical Regulatory Standards

Some readers may be interested in what standards were used to control doses to the public from releases of radionuclides to the Columbia River from 1964-1966. Previously published dose estimates (whole body) were below the 1964-1966 standard of 0.5 rem, whole body (Foster and Wilson 1965; Foster, Soldat and Essig 1966; Foster, Moore and Essig 1966; Honstead and Essig 1967; and Honstead, Essig and Soldat 1967). This historical standard does not translate directly to today's standard for DOE facilities, which is 0.1 EDE (rem). However, few, if any, Richland residents were likely to have received doses from the river pathways in 1964-1966 that were greater than today's limit.

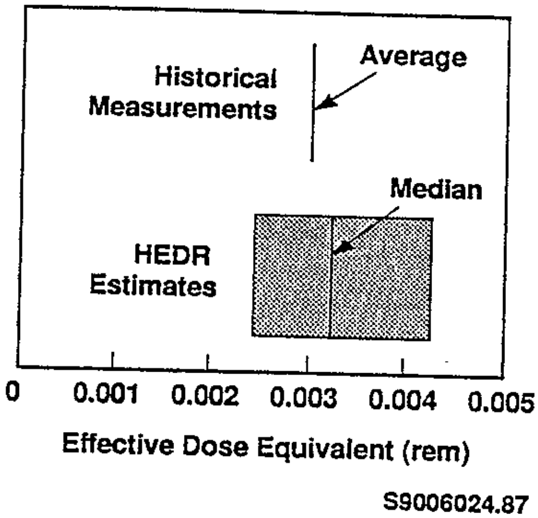

FIGURE 5.13. Doses from Zinc-65 Measured by Whole-Body Counter Compared with HEDR Dose Estimates for Richland Residents, 1964-1966

6.0 Comparison And Extrapolation of Dose Estimates from the Air and River Exposure Pathways

This chapter provides the reader with two more perspectives from which to view the Phase I preliminary dose estimates. The amounts of radiation received from the air exposure pathway are compared with those from the river exposure pathway. Then, the Phase I estimates are discussed in terms of where they might fall in the range of possible dose estimates from 1944 to today.

6.1 Comparison

Doses from the air pathway in 1944-1947 were generally higher for the downwind population than were doses from the river pathway from 1964-1966.

In terms of doses from the Columbia River pathway, some individuals who ate large quantities of fresh, non-migratory fish from upstream of Richland and downstream of the reactors might have had among the highest doses. These highest Columbia River pathway doses are less than 1% of the doses estimated for infants who lived immediately downwind of Hanford and who drank milk from cows fed on pasture during 1945.

6.2 Extrapolation of Preliminary Dose Estimates to 1944-1990

As discussed, iodine-131 releases accounted for most of the offsite population exposures from the air pathway in the early years, and these exposures were greater than exposures that resulted from later, episodic releases of iodine-131 or other radionuclides such as ruthenium-103/106. Releases to the Columbia River increased gradually from 1944 through the early 1950s. As the number and power levels of the reactors increased, releases to the river increased until they reached a plateau during the period 1959-1965. Between 1964 and 1972, all original reactors (designed to release contaminated cooling water to river) were shut down, so that only N Reactor was operating.

In summary, public exposures to atmospheric releases of radionuclides from Hanford were highest in the early years of operations and declined sharply except for small amounts released accidentally after the early 1950s. Public exposures to releases of radionuclides into the Columbia River increased steadily until the late-1950s and reached a plateau in the mid-1960s.

Air Pathway, 1948-1990

Preliminary dose estimates were made in Phase I for the period 1944-1947, based on the air pathway only, and only on iodine-131. As discussed, iodine-131 is estimated to account for more than 95% of the doses from all airborne radionuclides during the period 1944-1947, and iodine-131 releases during that time accounted for more than 90% of all iodine releases from the Hanford Site (Figure 6.1). It follows that doses from iodine-131 during the period 1944-1947 are likely to account for up to 80% or more of all doses from any offsite release of radionuclides to the atmosphere from Hanford for the period 1944-1990.

Water Pathway, Other Times and Locations

Later phases will address dose estimates for periods other than from 1964 to 1966 and for populations downstream of the Phase I study area. Rough dose estimates for the drinking water pathway can, however, be extrapolated to earlier and later periods and to downstream locations.

Estimates of doses for the period 1957-1972, when the last of the original eight production reactors was shut down, are available in published reports and provide a reasonable estimate of doses to average and maximally exposed individuals in Richland. Doses for the period 1944-1956 can be extrapolated from estimates of power levels and from environmental measurements. As shown previously in Figure 5.6, power levels were considerably lower in the early years of operation when fewer reactors were operating, resulting in much lower releases of radionuclides to the Columbia River.

Extrapolations of dose estimates to the few downstream locations where communities used treated Columbia River water for drinking can be based on previously published measurements of radionuclide concentrations at Bonneville Dam or Vancouver, Washington. In general, concentrations of radionuclides that accounted for most of the drinking water dose at these downstream locations were about 10% of the concentrations at Richland.

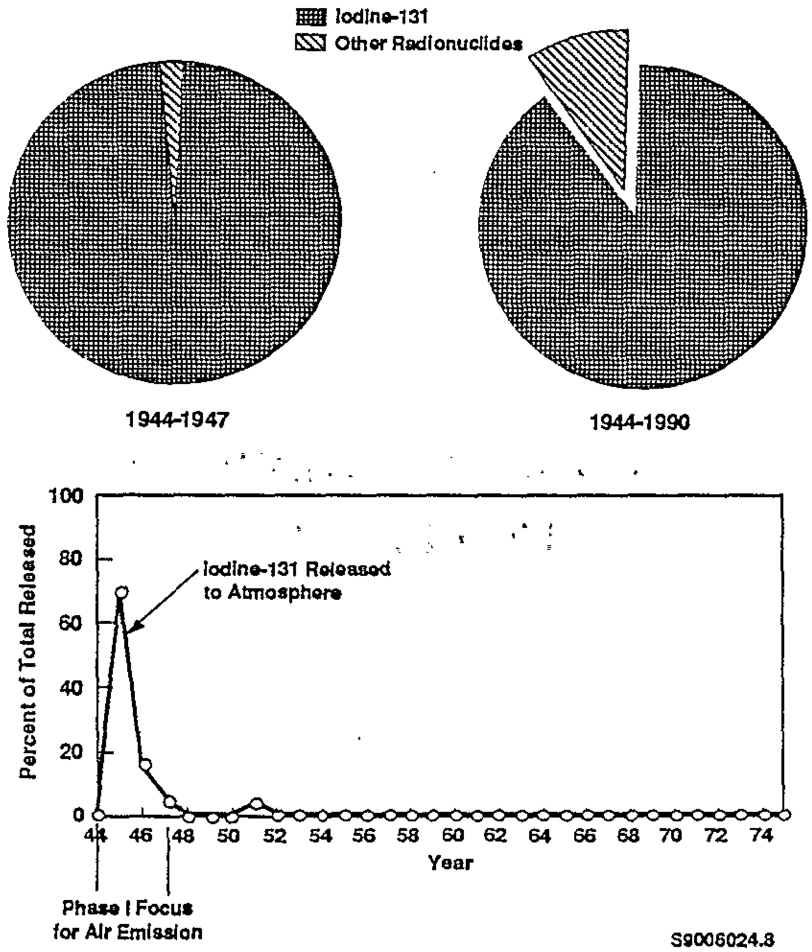

FIGURE 6.1. Iodine Releases from Hanford Separations Plants to the Atmosphere, Percents of Totals (Anderson 1974)

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7.0 References

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8.0 Glossary

Note: These definitions are written to apply specifically to the dose reconstruction project. The defined words may have slightly different meanings when used in other scientific contexts.

Background radiation - Radioactivity in the environment and from manmade sources. Natural radioactivity includes cosmic rays from space and radiation that exists elsewhere—in the air, in the earth, and in artificial materials that surround us. Manmade radiation includes that from X-rays and other medical procedures. In the United States, most people receive an Effective Dose Equivalent (rem) of about 0.36 of background radiation per year.

Calculated data - In dose reconstruction, quantities, such as the amount of a contaminant in the environment, that were calculated rather than measured. For example, because exact measurements of the amounts of vegetation cows ate in the 1940s are not available, scientists must calculate (estimate) the amounts based on other information.

Centers for Disease Control - The component of the federal Department of Health and Human Services based in Atlanta that provides research and public information services regarding human health issues. The Centers for Disease Control is working with the Fred Hutchinson Cancer Research Center to conduct the Hanford Thyroid Disease Study.

Code - A set of computer instructions that directs a computer in its operation.

Complementary cumulative distribution function (CCDF) - A statistical graph that shows the probability that the true value of something will be equal or greater than a specific value. The dose estimates are shown as complementary cumulative distribution functions to tell people how likely they were to have received more than a certain amount of radiation.

Decay, radioactive - How a radioactive nucleus, such as iodine-131, loses its radioactivity by spontaneously changing into a more stable nuclide, which may or may not be radioactive.

Declassification - A determination by an appropriate authority in accordance with approved classification policy or guidance that a classified document or material no longer contains classified information.

Demography - The study of the aspects of human populations, such as size, growth, density, distribution, and vital statistics. Demographic information—such as how many people lived where, how old they were, and what they ate—helps scientists estimate the amounts of radiation people may have received.

Department of Energy - See "U.S. Department of Energy."

Deposition - When material in the air falls to the ground. For example, some of the radioactive material emitted into the air from Hanford facilities fell on vegetation or crops.

Diffusion - When a substance introduced to a natural system spreads and dilutes as it moves through the system. An example is radioactive gases that are released into the air and carried by the wind through the environment.

Distribution - see "Complementary cumulative distribution function."

Dose - See "Radiation dose."

Downwind - In dose reconstruction, the geographic areas where the predominant winds carry radioactive materials from the Hanford Site.

Downwinder - people who live(d) in locations where predominant winds usually carried radioactive material.

Effective Dose Equivalent (EDE) (or EDE rem) - An estimate of the total risk of potential health effects from radiation exposure.

Environmental transport - How material moves through the environment. For example, radioactive material can be carried by the wind and fall onto crops.

Epidemiology - The study of the occurrence, causes, and severity of diseases in human populations.

Exposure pathway - The way people or animals come in contact with radiation. An example of an exposure pathway is radioactive iodine in the air depositing on pasture grass, which dairy cows eat. The radioactive iodine then appears in the cows' milk, which people drink, thereby exposing them to radioactive iodine.

Fred Hutchinson Cancer Research Center - Independent research organization and comprehensive cancer center in Seattle that is conducting the Hanford Thyroid Disease Study under the direction of the Centers for Disease Control.

Grid - A pattern of cross-hatched lines superimposed on the geographical study area to specifically locate each place. The grid is similar to the grid of a typical city street map. The grid is used in the part of the computer model that simulates movement of radioactive materials through the atmosphere.

Half-life - The length of time in which any radioactive substances will lose one-half of its radioactivity. Each radionuclide has a characteristic, constant half-life, which may vary from a fraction of a second to thousands of years. For example, iodine-131 has a half-life of 8 days. This means it will lose half its radioactivity in 8 days, half of the remainder in the next 8 days, half of what is left by 8 days later, and so on. After 7 half-lives, less than 1% of the original activity is left. For iodine-131, 7 half-lives take about 56 days.

Hanford Environmental Dose Reconstruction (HEDR) Project - A study to estimate the radiation dose the public could have received from nuclear operations at the Hanford Site since 1944.

Hanford Health Effects Review Panel - A panel convened by the Centers for Disease Control in 1986 at the request of the state of Washington and the Indian tribes to review and evaluate epidemiological data concerning possible health effects that may have resulted from Hanford nuclear operations.

Hanford Site - The 560 square miles of federally owned land in southeastern Washington that has been used since 1944 for nuclear reactor operations, nuclear fuel processing, radioactive waste management, environmental and energy research, and related activities.

Hanford Thyroid Disease Study - An epidemiologic study being conducted by the Fred Hutchinson Cancer Research Center in Seattle in collaboration with the federal Centers for Disease Control. The purpose of the study is to determine whether the risk of developing thyroid disease is increased among persons exposed to radioactive iodine released to the atmosphere from the Hanford Nuclear Site between 1944 and 1957.

Iodine-131 - a radioactive isotope of iodine produced in gas form in plutonium production reactors and released to the air as a gas when fuel was dissolved to extract the plutonium. In the human body, iodine tends to concentrate in the thyroid gland.

Measured data - Data that can be directly measured. For example, a person's height and weight can be directly measured. Measuring the kinds and amounts of radioactivity in the Columbia River help scientists estimate radiation doses.

MESOILT2 - A computer model that calculates the concentration of radioactive materials in the air for the large geographic area being studied for dose reconstruction. The MESOILT2 model was developed specifically for the dose reconstruction study. MESOILT2 calculates transport and diffusion, based on meteorological data from as many as 40 locations. It accounts for variations in space and time in atmospheric conditions between the point where contaminants are released and the points where they are deposited in the environment or contribute to exposure.

Millirem - One-thousandth of a rem.

Model - A set of mathematical equations that represent physical or chemical systems.

Nuclide - A species of atom having a certain number of protons and neutrons and a characteristic energy content in the nucleus. Some nuclides are radioactive (see "Radionuclide").

Order of magnitude - A range of values between a number and a number 10 times as large. For example, 10 is an order of magnitude larger than 1, and 100 is one order of magnitude larger than 10 and two orders of magnitude larger than 1.

Pacific Northwest Laboratory (PNL) - The research and development laboratory in Richland, Washington, where scientists are conducting the dose reconstruction project under the direction of the Technical Steering Panel.

Parameters - Any one of a set of variables in a model whose values determine the characteristics or behavior predicted by the model.

Pathway - See "Exposure pathway."

Population dose (population exposure) - The sum of the individual radiation doses received by people in a certain population group who were exposed to radiation.

Quality assurance - An integrated program of activities for ensuring that technical results are valid, defensible, and reproducible. Quality assurance includes all aspects of project activities that affect the results produced, from the choice of methods, to staff training, to data handling, and to reporting of results.

Rad - A measure of the amount of radiation energy absorbed by an organ such as the thyroid gland.

Radiation - Energy traveling in the form of rays, such as gamma rays, or as particles, such as beta-particles that are produced in various nuclear or atomic reactions. Radiation can come from human activity, such as the operation of the Hanford facilities, or from nature such as radon gas or the sun.

Radiation dose - Amount of radiation absorbed from the radiation by whatever the radiation is passing through.

Radioactive decay - See "Decay, radioactive."

Radionuclide - A radioactive element. There are several hundred known radioactive nuclides, both produced by humans and naturally occurring. Hanford's nuclear facilities released radionuclides to the air and water.

Rem - The dose in "rad" multiplied by a scaling factor that indicates the effectiveness of the particular radiation in doing biological damage. Equal "rem" doses imply equal biological damage.

Sensitivity analysis - An analysis that estimates the amount of variation in a computer model's output resulting from the variation in the model's input. For example, scientists use sensitivity analyses to determine which of the information that goes into the model has the most significant effect on the resulting dose estimates. That information will be made as accurate and precise as possible so that the resulting dose estimates will be as accurate as possible.

Separations Plants - Chemical processing facilities where the plutonium and the fission products in irradiated nuclear fuel are chemically separated.

Source term - The amount, type, and location of radioactive materials released to the environment.

Technical Steering Panel - Independent, 18-member panel that directs the dose reconstruction work. Panel members include scientific experts, representatives of the states of Washington and Oregon, Native American tribal representatives, and a public representative.

Thyroid - A small gland in the front of the human neck that regulates metabolism. The thyroid gland absorbs iodine.

Transfer factor - The fraction of a radionuclide that is transferred in a certain amount of time from one "compartment" to another in an environmental model. For example, the amount of radioactivity on pasture grass (compartment one) that is eaten (transferred to) by a cow (compartment two) each day (time).

Transport - See "Environmental transport."

Uncertainty - The degree of confidence in data or a computer model. A dose estimate cannot be 100% certain because it is an estimate of something that happened in the past. Because scientists must estimate some of the information they use for calculating doses, that uncertainty is reflected in the doses. That is why doses are expressed in terms of a distribution of values and their likelihood instead of a single specific dose value.

Upwind - In dose reconstruction, the geographic areas where the wind only occasionally carries radioactive materials from the Hanford Site.

Validation - The process of confirming that the conceptual model accurately represents processes that it is simulating. The model is validated by comparing calculations with field observations and experimental measurements.

Verification - The process of confirming that the conceptual model is numerically correct. The model may be verified by comparing various computer codes or by comparing outputs of numerical codes with analytical solutions.

Whole-body count - The measurement of the amount of radioactivity contained in a person. A whole-body count is used to determine whether a person has been exposed to an internal deposition of radioactivity greater than the naturally occurring amount.

Appendix
Titles of HEDR Publications

Title	Author	Publication Date	Publication No.
Hanford Environmental Dose Reconstruction Project Monthly Report	Haerer, HA	Monthly	PNL-6450 HEDR
Work Plan for the Hanford Environmental Dose Reconstruction Project	Haerer, HA	1989	PNL-6696 HEDR REV 1
Proposed Approach for Developing Information on Population Food Consumption and Lifestyles of Native Americans in the HEDR Study Area	Rhoads, RE, and Bruneau, CL	1989	PNL-6803 HEDR
Summary Report of HEDR Workshop on Sensitivity and Uncertainty Analysis	Sagar, B., and Liebetrau, AM	1989	PNL-SA-16804 HEDR
Demographic, Agricultural, Food Consumption, and Lifestyle Research for the Hanford Environmental Dose Reconstruction Project	Beck, DM, et al	1989	PNL-6834 HEDR
Response to TSP Directive 88-4, Ground-Water Contamination Data	Freshley, MD	1989	PNL-6847 HEDR
A History of Major Hanford Operations Involving Radioactive Material	Ballinger, MY, and Hall, RA	1989	PNL-6964 HEDR
Summary of Workshop on Milk Production and Distribution, November 30, 1988 - HEDR Project	Beck, DM, et al.	1989	PNL-6975 HEDR
Feasibility of Using ^{129}I Concentrations in Human Tissue to Estimate Radiation Dose From ^{131}I	McCormack, WD	1989	PNL-6889 HEDR
Hanford Environmental Dose Reconstruction (brochure)	Bruneau, CL	1989	PNWD-1323 HEDR
Radionuclide Sources and Radioactive Decay Figures Pertinent to the HEDR Project	Heeb, CM	1989	PNL-7177 HEDR
Uncertainties in Source Term Calculations Generated by the ORIGEN2 Computer Code for Hanford Production Reactors	Heeb, CM	1989	PNL-7223 HEDR
Atmospheric Transport and Dispersion Modeling for the Hanford Environmental Dose Reconstruction Project	Ramsdell, JV	1989	PNL-7198 HEDR
Preliminary Summaries for Vegetation, River and Drinking Water and Fish Radionuclide Concentration Data (DRAFT)	Woodruff, RK	1989	PNL-SA-17641 HEDR

Title	Author	Publication Date	Publication No.
Atmospheric Transport Modeling and Input Data for Phase I of the Hanford Environmental Dose Reconstruction Project	Ramsdell, JV, and Burk, KW	1989	PNL-7199 HEDR
Fission-Product Iodine During Early Hanford-Site Operations: Its Production and Behavior During Fuel Processing, Off-Gas Treatment, and Release to the Atmosphere	Burger, LL	1989	PNL-7210 HEDR
The Hanford Environmental Dose Reconstruction Project: Background Information (flier)	Byram, SJ	1989	PNL-SA-17658 HEDR
Summary of Literature Review of Risk Communication	Byram, SJ	1989	PNL-7226 HEDR
Milk Cow Feed Intake and Milk Production and Distribution Estimates for Phase I	Beck, DM	1989	PNL-7227 HEDR
Estimations of Traditional Native American Diets in the Columbia Plateau	Hunn, ES and Bruneau, CL	1989	PNL-SA-17296
Estimates of Columbia River Radionuclide Concentrations: Data for Phase I Dose Calculations	Richmond, Walter	1990	PNL-7248 HEDR
Evaluation of Thyroid Radioactivity Measurement Data From Hanford Workers, 1944-1946	Ikenberry, T	1990	PNL-7254 HEDR
I-131 in Irradiated Fuel at Time of Processing From December 1944 Through December 1947	Morgan, LG	1990	PNL-7253 HEDR
Population Estimates for Phase I	Beck, DM	1990	PNL-7263 HEDR
Estimates of Food Consumption	Callaway	1990	PNL-7260 HEDR
Soil Ingestion by Dairy Cattle	Darwin, RF	1990	PNL-SA-17918 HEDR
Computational Model Design Specification for Phase I of the Hanford Environmental Dose Reconstruction Project	Napier, BA	1990	PNL-7274 HEDR
Selection of Dominant Radionuclides for Phase I of the HEDR Project	Napier, BA	1990	PNL-7231 HEDR
A Preliminary Examination of Audience-Related Communications Issues: Hanford Environmental Dose Reconstruction Project	Holmes, CW	1990	PNL-7321 HEDR
MESOILT2, A Lagrangian Trajectory Climatological Dispersion Model	Ramsdell, JV	1990	PNL-7340 HEDR
Draft Summary Report	HEDR Staff	1990	PNL-7410 HEDR
Draft Air Pathway Report	HEDR Staff	1990	PNL-7412 HEDR
Draft Water Pathway Report	HEDR Staff	1990	PNL-7411 HEDR

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